Innovation brings satellite-based train CONTROL within reach

As Amtrak's California Zephyr leaves Chicago Union station, the DGPS aerial for the PTC pilot project is visible on the roof of the lead loco (arrowed), although this particular train will not traverse the Mazonia – Springfield route Photo: Ron Goodson/www.railnut.net

Current projects suggest that the falling cost and enhanced performance of satellite navigation systems offer the potential to increase capacity and improve safety whilst saving on trackside equipment

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AROUND THE world, main line railways are adopting communications-based train control in place of conventional signalling as a way to improve capacity and performance, and reduce the costs of installing and maintaining lineside equipment.

CBTC relies on continuous updating of train location, and this is where the various approaches differ. Positioning methods include track circuits, balises or transponders, tachometers and other odometry methods, and now global navigation satellite systems (GNSS). The advent of EGNOS, Galileo and other satellite innovations are improving the accuracy, reliability and coverage of GNSS, helping railways reap the benefits of CBTC.

The European Train Control System has standardised on balises as the principal method of train location, but some railways outside Europe regard them as too costly. GNSS offers the potential to reduce or eliminate the need for balises in new applications around the world, and could also simplify the deployment of ETCS in Europe.

Table I lists a number of initiatives around the world where railways and suppliers are testing and implementing GNSS-based train control.

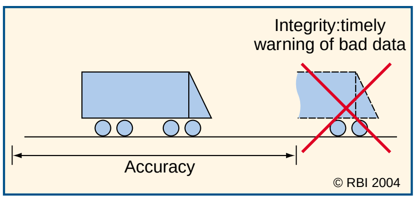

Fig 1. Greater **accuracy** *means being able to state that a train is on a shorter section of track.* **Integrity** *implies a timely warning if the train moves outside this section. Europe's CENELEC standards, for example, require that the probability of failing to provide such warning be 10^{-9} per hour of operation*

Accuracy, integrity and cost

A critical objective for CBTC is to optimise the braking curve – a train should start to brake neither too early nor too late. This requires continuous updating of every train's location with both adequate accuracy and full integrity (Fig 1). Continuous positioning allows the train control system to calculate its speed and, when combined with train and line characteristics, braking distance.

In CBTC, better positioning accuracy generally costs more. But more accuracy also lets a railway increase capacity by reducing safety margins for braking on either existing blocks, short virtual blocks or moving blocks. On a busy line, a railway will tend to invest in more accuracy for more capacity. On lower-density lines, however, the railway may only want to pay for high accuracy in some places. Whatever the required accuracy, however, a CBTC positioning system must maintain full integrity.

The impending completion in 2008 of the European Galileo network, joining the American GPS and Russian GLONASS constellations, together with related innovations, have spurred a resurgence of interest in using satellite technology for train control. But concerns remain. These include the accuracy, integrity and reliability of the signals, satellite masking, and reflected signals that falsify position computations. Some railways are also uncomfortable about relying on outside parties – and foreign powers.

To calculate its position, a GNSS receiver measures the transit time of signals from several satellites. Other systems are used to augment location accuracy. In differential GPS, ground stations monitor the GNSS accuracy and broadcast corrections to nearby mobile receivers. Wide-area augmentation systems (WAAS) broadcast corrections from geostationary satellites. Three European EGNOS satellites are now broadcasting GPS and GLONASS corrections, and trigger an alarm within 6 sec of any loss of integrity.

From 2008, the 30 European Galileo satellites plus EGNOS promise built-in integrity monitoring and a formal service guarantee, which the current GNSS systems lack. The interoperability of GPS and Galileo will improve GNSS coverage, and their technical independence will provide redundancy.

In the near future, we expect to see the introduction of pseudo-satellites (pseudolites) to provide positioning signals within tunnels and other masked areas. The wide range of potential non-railway users will probably be able to support augmentation and coverage extension schemes because it will be possible to spread the costs over many customers.

Signals reflected from buildings and other objects can falsify position calculations (Fig 2). Vegetation, terrain, buildings or tunnels can also mask some

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This article is partially based on published reports from the projects listed in Table I, and on input from a number of experts around the world, to whom the authors wish to express their gratitude

Bombardier Transportation is working on the INTEGRAIL project in Europe. Signals from the nose-mounted GSM-R and GNSS antennae are fed to a processor in the locomotive cab (above); the laptop is only being used for test and monitoring purposes

or all satellites from the railway alignment. In location systems implemented to date, other positioning methods are generally used to confirm GNSS information and bridge any gaps in coverage. These can include balises, track circuits and odometers, for example.

However, wheelslip, slide and wear can skew distance measurements on axle-mounted tachometers by up to 5%. For better train odometry, the GNSS-based systems currently under development generally make use of other sensors. These can include accelerometers, gyroscopes, or the sensing of track features using optics, eddy currents or radar. The positioning system integrates sensor data with a track database, and continuously updates the end points of the track section containing the train.

System designers must weigh the cost of integrating each type of sensor (some of which need to be installed under the train) against its contribution to overall accuracy and the maintenance of integrity.

Other concerns about satellite-based train location include:

- Discrimination between parallel tracks. Current GNSS cannot do this alone. Solutions rely on additional inputs such as balises, track circuits, point locations as detected at the interlockings, and on-board sensing of the train's route through pointwork.
- Stabled, stationary and creeping trains, where motion-based sensors cannot confirm the GNSS position data.
- Accuracy and integrity of the track database, particularly during infrastructure maintenance or remodelling.

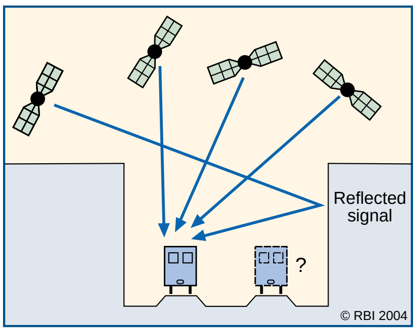

Fig 2. To calculate its position, a GNSS receiver typically measures the transit time of signals from four or more satellites. This assumes a direct path from satellite to receiver. In the rail environment, however, some signals reach the receiver only after bouncing off buildings or other objects. This phenomenon, known as multipath, worsens positioning accuracy unless the receiver can filter out the slightly weaker reflected signals

Falling cost, improving accuracy

The cost of using GNSS positioning for train control is likely to fall over the next few years. Because all trains operate under the same satellites, suppliers should be able to develop common systems for applications right across the world market instead of technologies limited to one continent or country.

Galileo's specifications include the provision of a 'safety-of-life' service targeted specifically at safety-critical users in the maritime, aviation and rail markets 'whose applications or operations require stringent performance levels'. We anticipate that this will spur innovations in all transport sectors.

The huge potential market will bring forth augmentation, monitoring and pseudolite systems that can benefit all users, including railways. In their search for solutions to the reflection and masking of GNSS signals in particular, railways should be able to profit from developments for the much larger automotive market.

GNSS-based positioning will progressively prove that its accuracy, coverage, reliability, integrity and cost can meet railway requirements. This should bring three main benefits of CBTC within reach. On lines with conventional signalling, GNSS-based positioning will allow the elimination of much trackside equipment and increased capacity. On lines that are currently without movement authority enforcement, GNSS also promises better safety.

Integration with ETCS

ETCS is Europe's first attempt at developing a true international standard for train control systems. The basis for train positioning in Level 1 and Level 2 is the track-mounted Eurobalise, augmented by odometry. Suppliers and railways argue that the balise uses simple and proven transponder technology.

This is in direct contrast to major railways in Australia, North America and Russia, which have rejected the use of balises in their new CBTC installations. The detractors point to the cost of installing and maintaining large numbers of balises between the rails – especially on busy or remote lines – and the corresponding antennae under each driving vehicle. Increasing use of low-value materials and better installation methods should mitigate against the threat of balise theft and vandalism.

In Europe, GNSS promises to improve positioning between ETCS balises compared to odometry, and possibly allow a reduction in the number of balises required. The two systems together will provide redundancy for both safety and reliability. Given Europe's variety of traffic densities, the

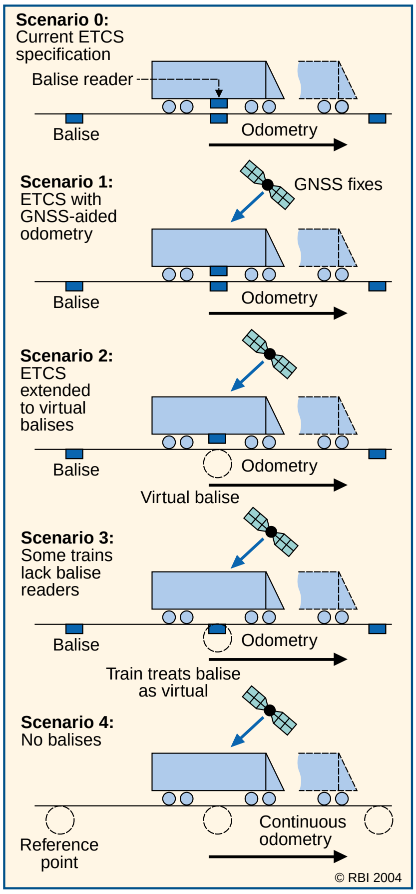

Fig 3. Starting from the current ETCS specification (Scenario 0), there are two approaches for combining GNSS with balise-based train location systems. Scenario 1 simply uses GNSS positioning between the existing Eurobalises. In Scenario 2, GNSS positioning can replace some balises, although the train will continue to report its passage over 'virtual balises'. Assuming full integrity, GNSS-based accuracy may suffice, especially on low-density lines. Balises will still be required for train location near pointwork, where GNSS signals are masked, and in busy areas. Future advances in the accuracy and coverage of GNSS might let some ETCS trains run without a balise antenna (Scenario 3). This could permit migration away from balises altogether in the longer term (Scenario 4)

CVRD is using these 235 x 60 x 19 mm balises from Alstom, concealed within the sleepers, to provide train location data for its new train control system on the Carajás Railway, in conjunction with non-augmented GPS

urgency of cross-border interoperability, and rapid GNSS innovation, implementing both balise and GNSS-based positioning should give Europe's railways invaluable flexibility (Fig 3).

GNSS-based positioning may also allow railways to remove at least some track circuits or axle counters, saving on maintenance costs. However, track circuits have a number of functions. For example, some CBTC systems rely on track circuit timings in lieu of balises.

Track circuits can also detect some kinds of broken rail, although the current switch to axle counters for train location has spurred the development of alternative systems to monitor track integrity without track circuits.

Improved end-of-train devices on freight trains and databus networks on passenger trains could provide the vital monitoring of train integrity. Combined with GNSS positioning, such devices could allow railways to remove track circuits on plain line, and retain them only in pointwork zones to detect unequipped, stabled and stray vehicles.

Where train integrity monitoring does not rely on track circuits, their length does not constrain the train headway. This is the theory behind ETCS Level 3, which envisages an advanced CBTC using moving or short virtual blocks to gain capacity. Level 3 development has made little progress to date, but high-integrity GNSS location systems may offer a more cost-effective way forward.

Meanwhile, two other GNSS-based functions are under development and deployment to increase operational safety and reduce delays. Experiments are being conducted with GNSS-equipped trains that can trigger the warning cycle and close the barriers at each level crossing a constant time before the train's arrival, no matter what its speed. GNSS-based systems are also being used to inform both infrastructure work sites and approaching trains about each other's existence and position. ■

Table I. World-wide GNSS applications

Australia: Over the next decade, ARTC is planning to implement its GNSS-based ATMS on around 8 000 route-km. Based on North America's jointly-developed PTC technology, ATMS will use track circuits only in areas of pointwork, and will not use fixed balises.

Brazil: CVRD is equipping its 900 km Carajás Railway with a new train positioning system based on a combination of tachometer, non-augmented GPS and balises. Each 235 x 60 x 19 mm balise, whose plastic shell has no resale value, is concealed within a hole inside a sleeper (above). Full implementation of the system will eventually permit the removal of track circuits and axle counters.

The same company's 7 000 km Ferrovia Central Atlântica, which lacks any conventional signalling, is now using non-augmented GPS to monitor the distance to danger points and enforce movement authorities. This system uses no balises.

China: The Ministry of Railways unveiled its plans for a Chinese Train Control System in 2002. CTCS Level 4 foresees moving block, using GNSS or balises for positioning, on-board train integrity monitoring and track circuits only at stations.

Europe: A number of projects have been testing GNSS-based positioning systems in the context of ETCS.

- Ecorail is developing level crossing control.
- Integral has been testing the integraton of train location data from multiple sensors.
- Gaderos has been proving the feasibility of using GNSS positioning in ETCS and developing a testbed for locators.
- Locoprol (RG 8.03 p498) has been developing low-cost GNSS positioning for low-density routes without additional sensors.
- Rune is examining the virtual balise and ways of providing better information to drivers on conditions ahead.
- Traposat proposes to pursue tunnel coverage and an open architecture for GNSS and related on-board equipment.

India: Indian Railways is developing a GNSS-based anti-collision device that monitors trains and applies brakes independently of the conventional signalling system.

North America: In Michigan, Amtrak is using GNSS-based ITCS in commercial operation for 145 km/h passenger trains on the New Bedford – Kalamazoo section of its Chicago – Detroit line (RG 8.96 p496).

The jointly-developed GNSS-based Positive Train Control system is set to enter commercial service on a 193 km line in Illinois in 2005. The Mazonia – Springfield line carries a mix of 177 km/h passenger trains with freight traffic. Conventional signalling has been retained, mostly so that unequipped trains can still use the line. On-board sensors detect a train's route through pointwork. Goals include the establishment of interoperability standards for North America.

Unlike Amtrak's non-GNSS train control system in the Northeast Corridor (Acses), neither ITCS nor PTC use balises. Alaska Railroad is also developing its own GNSS-based train control system.

Russia: RZD has equipped around 10 000 driving vehicles with the GNSS-based KLUB-U system for enforcement of movement authorities. Train positioning is provided by track circuit timings, tachometer, GPS and Glonass signals, augmented by radio ranging in stations. The system uses no balises. Its design provides for the eventual removal of track circuits if and when GNSS positioning and on-board train integrity monitoring are deemed sufficiently accurate.

South Africa: Spoornet has requested bids for a new train control system for its 861 km Ore Export Line between Sishen and Saldanha, and expects proposals to involve the use of GNSS positioning technology. Spoornet has ruled out the use of track circuits to avoid maintenance costs. Some form of fixed 'marker' (or balise) may be required to reset the on-board odometry.

L'innovation met le suivi des trains par satellite à portée de main

Actuellement dans le monde, les projets en cours de réalisation laissent à penser que la diminution des coûts et l'amélioration des performances de la navigation par satellite rendent cette dernière adéquate pour le suivi des trains. On s'attend à ce qu'en 2008, le lancement du réseau européen Galileo, améliore la précision et la couverture des systèmes globaux de navigation par satellite, en particulier pour les applications liées à la sécurité. GNSS promet d'améliorer la sécurité et de réduire la nécessité d'employer les balises et autres équipements installés dans la voie et, ainsi, diminue à la fois les coûts en capital et en maintenance. Il permettra l'introduction du block à cantons glissant afin d'accroître la capacité de ligne, pourvu que l'intégrité des trains soit maîtrisée

Innovationen bringen Satelliten-gestützte Zugsüberwachung in Griffnähe

Projekte, welche an verschiedenen Orten dieser Welt aufgebaut werden lassen darauf hindeuten, dass die sinkenden Kosten und verbesserten Leistungen der Satelliten-navigation es möglich erscheinen lassen, dieses System auch für die Zugsüber-wachung einzusetzen. Der 2008 erfolgende Start des europäischen Galileo-Netzes soll die Genauigkeit und die Flächendeckung von globalen Navigationssatellitensystemen verbessern, insbesondere für sicherheits-relevante Anwendungen. GNSS verspricht eine verbesserte Sicherheit und ein geringerer Bedarf an balisen und anderen-ortsfesten Ausrüstungen, was zu geringeren Kapital- und Unterhaltskosten führt. Sie ermöglicht die Einführung von Wanderblock zur Steigerung der Streckenkapazität, vorausgesetzt, dass die Integrität des Zuges ebenfalls überwacht werden kann

La innovación pone el control de trenes por satélite al alcance de la mano

Los proyectos que se están implementando en todo el mundo apuntan a que la caída en los costes y al mayor rendimiento de la navegación por satélite la hacen muy apta para la detección de trenes. El lanzamiento de la red europea Galileo en 2008 nos ofrecerá, según se espera, una mejora en la precisión y la cobertura de los sistemas globales de navegación, particularmente en las aplicaciones con niveles de seguridad críticos. GNSS promete mejorar la seguridad y reducir la necesidad de balizas y de otro equipo montado en vía, disminuyendo así los costes de capital y de mantenimiento. Permitirá asimismo la introducción de bloque móvil para aumentar la capacidad de la línea, siempre y cuando la integridad del tren pueda controlarse también