Using CBTC as an energy-saving tool

Siemens Mobility has used a section of London's Elizabeth Line fitted with CBTC to study how its Trainguard MT technology has enabled revenue earning trains to save energy without compromising the customer experience.

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Photo: Tom Nicholson

Metro ridership has increased over recent decades, and communications-based train control has become the default technology to handle this increasing ridership. CBTC has emerged as a *de facto* international standard for train control on urban railways. But the technology is not just about maximising network throughput, it can also offer important benefits in terms of energy consumption at a network level.

Metro and urban rail systems are among the most energy-efficient forms of land transport. Railways and metros that use CBTC can use the various signalling functions to help reduce energy consumption. As the trains are controlled in a highly automated manner, it becomes possible to replicate energy-saving driving patterns day in, day out.

CBTC and energy saving

Modern moving block principles minimise train headways down to the physical limits of the infrastructure. This means that the throughput of a metro line can be maximised within the limits of the fixed assets available.

CBTC systems can deliver all the information needed for energy efficient driving (including train position, track topology, braking curves and so on) to the train's onboard control units, as well as making it available to the control centre. Combined with intelligent driving strategies and algorithms to analyse energy use, this forms the basis for a substantial reduction in energy consumption and greenhouse gas emissions.

CBTC systems can help to save energy in four main ways:

- **Train management.** By using topology data from the track database (gradients, curve radii, etc) together with online timetable data from the traffic management software, every run between two stations can be optimised using the onboard ATO to deploy intelligent coasting algorithms.

  Academic research has shown that an energy-optimal driving trajectory consists of four driving states: full acceleration, cruising, coasting and full braking.

Siemens Mobility has studied the relationship between CBTC signalling and energy consumption using real-world data from the Paddington – Bond Street section of London's Elizabeth Line.

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driving states in an energy-optimal driving trajectory

- **Line management.** CBTC supports various measures which can be delivered in parallel. For example, intelligent algorithms can amend the operational parameters dynamically to manage energy consumption depending on passenger volume. When passenger volumes are low, the dwell times can be decreased and sectional running times extended commensurately to conserve power use without compromising the timetable. Dwell times can also be adapted dynamically to synchronise the arrival and departure of trains at stations, minimising traction power spikes and making the most of the regenerative braking ability of the trains to feed power back to the supply.
- **CBTC network management.** At a network level, the main measures are the optimisation of connections between routes and the

co-ordination of train movements in times of disruption. For example, in the case of one train being delayed, the CBTC algorithms should be able to account for that delay by injecting more padding into the timetable for pathing or connecting at a junction further down the line. Both trains would be delayed, but would continue their journeys from the junction station at the same time because both trains could use the delay impact for energy reduction.

- **Complete Mobility Management.** CMM refers to the means through which a CBTC-equipped metro can offer optimised connections with other modes of transport. This in turn should support modal shift towards rail.

A case study in London

Many of the benefits of CBTC have been demonstrated on London's cross-city Elizabeth Line, which opened fully in May 2022. This has a total network length of 118 km, of which only 22 km is newly built. A Y-shaped set of twin-bore tunnels through central London

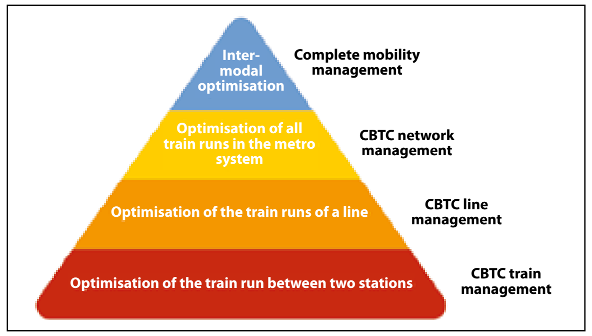


Fig 1. How to enable energy savings on a metro or suburban rail line fitted with CBTC.

serving 10 stations connects with the legacy Great Western and Great Eastern main lines at each end.

From a signalling perspective, only the newly built core is fitted with CBTC. The western route is partially fitted with ETCS, while elsewhere the signalling still relies on legacy electro-mechanical systems. The tunnel section is equipped with Trainguard MT supplied by Siemens Mobility. Platform screen doors are fitted at the underground stations to support semi-automated operation to GoA2.

Trainguard MT enables high-frequency, automated train operation through the central section. It is also delivering a reduction in energy use in this section, as the ATO and CBTC combine to ensure the time available for each run between stations is exploited in the most energy efficient way.

Gathering the right data

As the line has been fully operational for some time, it has been possible to analyse energy consumption data collected directly from the rolling stock interface. This does not rely on any simulation — the data were collected between March and December 2023, and the analytical work was undertaken last year.

Capturing energy data from the trains allows a very accurate assessment of the nominal energy consumption. To evaluate the train control system's capacity to support energy-efficient operation, we analysed data exclusively from the ATO section.

To make an assessment about savings, it is necessary to compare an optimised value against a reference or baseline value. The aim is to determine the minimum and maximum energy consumption between two stations. The baseline is the highest energy consumption, derived from the trip where the speed curve runs closest to the maximum permitted speed, resulting in the shortest possible trip time. This baseline varies between different stations and by direction of travel. Any other run in this section can then compared against this baseline.

There is a defined minimum and maximum running time between two given stations. These are derived from the physical limitations of the rolling stock, as well as from what the operator regards as acceptable in the working timetable.

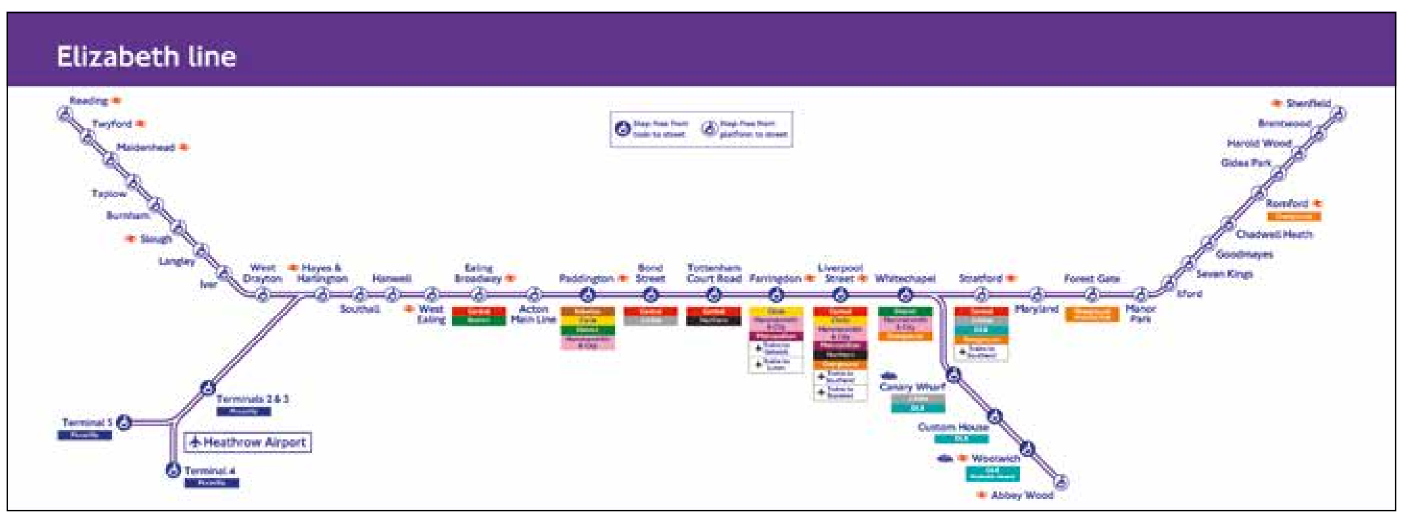
The more sectional run time available, the greater the potential for energy saving. If only the minimum run time is available, there is zero potential for savings, as the train has to drive as close as possible to the permitted speed curve. Conversely, the highest savings can be found on journeys where the available time between two stations approaches the maximum value.

This analysis focuses on Paddington and Bond Street stations, where the operational data showed the largest variation in sectional run times and vehicle weights. There was also an elevation change of 18 m.

Fig 2 illustrates two trips between Paddington and Bond Street, a distance of about 3 km. This compares the baseline energy consumption to a

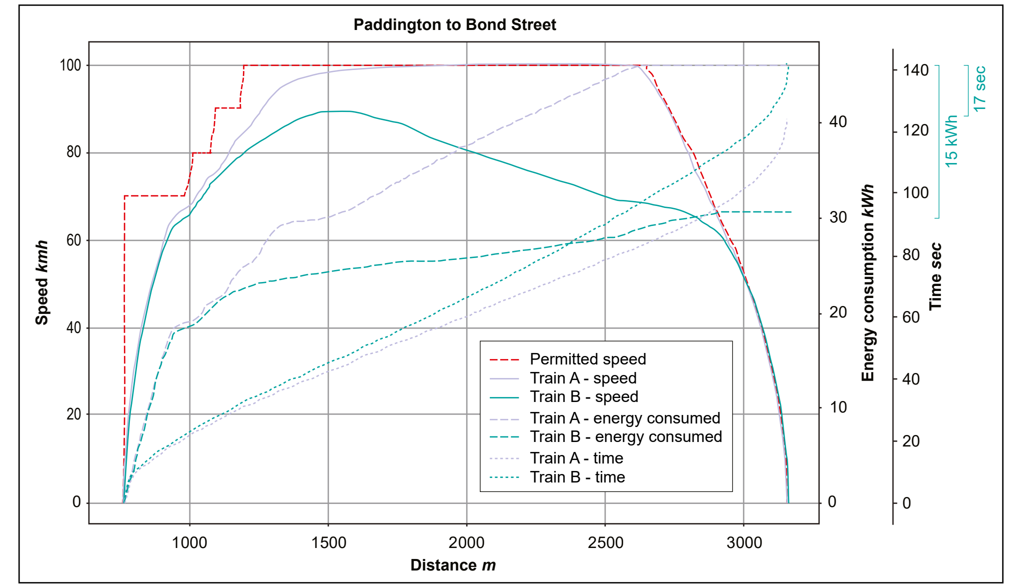
Table I. The potential for saving energy when running between Paddington and Bond Street stations

Time *sec*	Energy used *kWh*	% saved through optimisation
Descending gradient (PAD – BDS)		
125	48·0	n/a
130	37·6	21·7
135	30·8	35·8
140	27·7	42·3
143	27·6	42·6
Ascending gradient (BDS – PAD)		
130	56·4	n/a
135	48·8	13·4
140	42·7	24·2
145	38·1	32·5
150	34·9	38·2
155	33·1	41·3

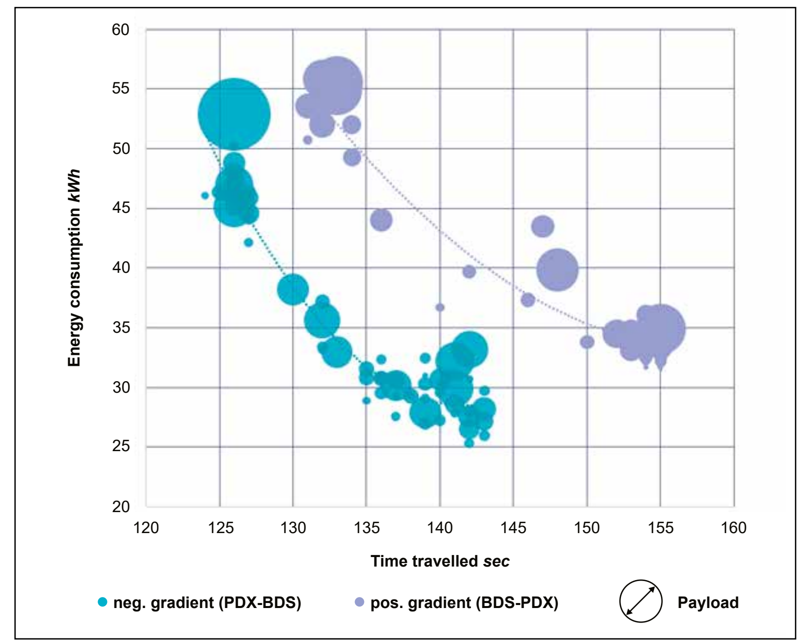


journey that lasts 17 sec longer and is optimised for energy efficiency by Trainguard MT.

The dashed red line indicates the maximum permitted speed. The two trips differ in their train speeds throughout the journey: The first trip (represented by the solid purple line) closely follows the permitted speed, resulting in a trip time of 123 sec (dotted purple line), the second trip (solid green line) utilises the time reserve allocated by the ATO tool. The train reaches a lower maximum speed and begins coasting from a distance of 1 500 m. This results in a longer trip time (140 sec) and a lower energy consumption. The energy consumption is represented by the dashed lines, with purple representing the first trip and green the energy-optimised trip. Overall, there was a reduction in energy consumption of approximately 33%.



Above: Fig 2. A comparison of two train runs between Paddington and Bond Street stations.



Left: Fig 3. The impact of schedule, gradient and vehicle payload on energy consumption.

Key factors identified

The data sets collected enable a detailed examination of how key factors such as schedule, vehicle payload and gradient affect energy consumption.

Fig 3 illustrates two distinct patterns: one for downhill trips from PAD to BDS and another for uphill journeys from BDS to PAD. Each dot represents a single train run, with dot size corresponding to vehicle payload — the bigger the dot, the higher the train weight including passengers.

The data indicate that, aside from the expected lower energy consumption for slower and downhill journeys, the variation in payload has a minor impact. The primary influencing factor is the schedule, with a clear relationship between travel time and energy consumption. Trips with slightly longer durations compared to the fastest possible run can offer significant energy savings. Between the two stations, a trip time of 130 sec consumed less than 80% of the energy than a run lasting 125 sec when operating under Trainguard MT. Table I shows the average energy consumption for the different trip times depicted by the regression curves in Fig 3.

The analysis also suggests that energy consumption depends to a large extent on track layout and direction of travel. This highlights the importance of examining operational data from revenue service to identify potential savings without compromising the service quality. The improved understanding could then be used to generate optimised working timetables.

The 'real-world' data also indicate that timetable 'padding' is the main lever for energy efficient operation from station to station using intelligent ATO coasting algorithms.

Based on these findings, a number of interventions can be recommended for future CBTC projects where energy saving is a goal:

1. Energy consumption data should be provided transmitted by the rolling stock to the onboard CBTC unit via a direct interface;
2. Energy consumption data should be collected from customer operations on specific track sections in order to capture the combined effects of the train properties (rolling resistance, air resistance, drivetrain efficiency and so on), track layout design, and gradients;
3. This data can then be used to perform a station-by-station and direction-dependent analysis to identify areas offering the highest energy-saving potential, typically focusing on available travel time for each given section of the route;
4. The analysis results can be used to develop an energy-optimised timetable while adhering to performance needs, individual customer targets, and other regulatory and stakeholder requirements.

This approach could also be applied retrospectively to lines where CBTC is already in use, to ensure that the full route-level operational benefits of the technology can be captured.

43%

Maximum reduction in energy consumption that could be achieved when optimising a Paddington – Bond Street journey using Trainguard MT