LONDON UNDERGROUND SIGNALLING
A HISTORY
by Piers Connor
1. FROM TIME TO SPACE

A NEW SERIES

Many readers of this journal will be familiar with my articles on London Underground rolling stock history and development. In my series 'The London Underground Electric Train' (published in *Underground News* between July 2005 and October 2008), I covered some of the details of the signalling equipment used on the Underground and I thought it would be worth expanding the signalling parts into a new series and, in the process, I could cover London Underground's signalling system history and development. So this article is the first of a new series on LU signalling, beginning with how railway signalling developed in Britain up to the time of the opening of the first part of the Metropolitan Railway in 1863. To help me, I have persuaded Thomas Crame and MRFS to assist with proof reading and technical advice, for which I am most grateful.

TIME AND MOTION

When railways were first being developed in the early 19th century, it was assumed that traffic would behave like road traffic. Persons wishing to use the railway would furnish their own trains and locomotives and pay a toll for the use of the tracks, not unlike the commercial relationships between today's train operating companies and Network Rail. As Cyril Byles, writing in 1910[1] put it, "*The early conception of a railway was simply of an improved highway, of a road on which rails should take the place of macadam and on which the coaches should be drawn by engines instead of by horses. The earlier railway Acts, indeed, contemplated the provision of the road alone by the railway company, the vehicles being supposed to be the property of the users of the railway exactly as coaches and wagons belonging to the public were run on the high roads*".

Very soon though, it became obvious that the railway would have to provide its own rolling stock and motive power since few people at that time had the expertise or the money to build their own trains. If the railway was to survive as a commercial enterprise, it had to develop its own traffic instead of waiting for users to turn up. By the time work began on the construction of the Liverpool and Manchester (L&M) Railway in 1826, the owners of the company realised that they needed to raise more money so that they could establish a "Carrying Department"[2]. They realised that they had to buy locomotives, coaches, wagons and the associated buildings and equipment and that they had to go back to parliament to get the necessary authority to raise more capital.

Soon after operations began, it became apparent that some form of traffic management was essential. Frequent stoppages and breakdowns had led to delays and interruptions to traffic and there were collisions. Although the L&M and most subsequent railways opened their operations with a fixed timetable for their passenger trains, their freight trains were initially run on an as required basis. Each station and some other locations, like level crossings, were provided with 'policemen', to advise train drivers on when and how to proceed. They used flags of various colours but these weren't always clearly visible and they soon evolved into boards or discs of various types mounted on fixed poles.

Experience with day to day operations soon showed, firstly, that trains were subject to breakdowns and other random stoppages and, secondly, a train wasn't easy to stop when confronted with a stationary train in front of it. Initially, an attempt was made to provide separation between trains by fixing the intervals between departure times. The generally accepted system was based on the idea that, at each station, you could allow a 5-minute interval between following trains if you told the driver of the second train that he should proceed at caution speed but, if the previous train had left 10 minutes earlier or more, you could tell the driver it was OK to run at full speed.

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1 Byles C, B. (1910), 'The First Principles of Railway Signalling' published by Railway Gazette, London, p.4. Cyril Beuzeville Byles (1878-1952) was the signal engineer of the Lancashire & Yorkshire Railway. In 1911, just after his book was published, he emigrated to work for the New South Wales Government Railways. The book wasn't that bad though. An interesting short biography of Byles by Ken Burrage was published in IRSE News No.150 November 2009.

2 'Liverpool and Manchester Railway Operations 1831-1845', by Thomas L. Donaghy, David & Charles, Newton Abbott, 1972, p.20.

As if more experience was needed, more experience soon showed that this system had its flaws, in that if a train failed somewhere between stations, the driver of the next train had no warning apart from a rule that a guard had to run back and warn him. With gradually increasing speeds and crude braking systems, collisions were inevitable and sometimes fatal. They were learning on the job and, eventually, the idea developed that, if you could find some way of letting the policeman at a station know that the last train to leave his station had reached the next station, you could offer the driver of the next train a clear road. This was a good solution in theory but it took some years to get it into practical application and it wasn't until the invention of the electric telegraph that the idea became a reality.

THE ELECTRIC TELEGRAPH

The idea that you could send messages over long distances using electricity gradually developed during the first 40 years of the 19th century, roughly in parallel with the development of electrical science itself. Various people, mostly scientists and academics but including the usual smattering of eccentrics, tried various communication systems, using battery fed circuits to operate bells or needles in such a way as to provide messages or indications over gradually increasing distances. They had to solve problems with poor battery performance, ineffective insulating materials, corrosion, the use of earth as a circuit return medium, the electrical performance of various types of wire, the effectiveness of different arrangements of magnets and coils and the vagaries of the weather, particularly damp and lightning damage.

At first the telegraph system comprised a number of needles that indicated letters so that text messages could be sent. These became known as 'the speaking telegraph' and were used on a number of railways but they were complex and slow, requiring a lot of wiring and skill and learning by the operators[3]. They weren't yet ideal for mainstream operations until Morse code was adopted on later versions.

Despite all these obstacles, by 1842, the science had progressed sufficiently for William Fothergill Cooke (later Sir)[4] to describe how, using the electric telegraph as the means of communication, a railway track could be divided into blocks, each being protected by a signal at its entrance.

No train would be allowed into a block until the next station had advised over the telegraph that the previous train had cleared it. This was the principle of one train in one block at one time and is still in force today.

Cooke had tried the technology on the London and Blackwall Railway in 1840 and, so he knew it worked and he published a pamphlet to promote it[5]. It eventually became known as the block telegraph system. Blocks were initially set out only between stations or through tunnels but take-up was slow and it was a long time (over 20 years) before it became generally accepted as a good idea and another 20 plus years before it was enshrined in law by the Regulation of Railways Act 1889.

COOKE & WHEATSTONE

The idea that the electric telegraph could be useful on the railways was put forward by William Cooke early in December 1836 but, at the same time, work on the electrical science of the telegraph system was being carried out by Charles Wheatstone. In February 1837, the two gentlemen met and formed what was intended to be an equal partnership to patent and develop the system. However, the relationship was not always a happy one and there were disputes over things like whose name should go on the documents describing the system and who was responsible for various modifications. It resulted in a case being considered for arbitration in 1840 by Prof. J.M. Daniell of Kings College, London and no less a person than Sir Marc Isambard Brunel. They seemingly resolved the situation by confirming a joint responsibility for the invention. It was accepted with public good grace by both parties but I suspect that privately, neither party was really satisfied, particularly Cooke, who seems to have been unfairly treated by Wheatstone.

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3 Preece, W.H., (1863). On Railway Telegrams, and the Application of Electricity to the Signalling and Working of Trains. In *Minutes of the Proceedings of the Institution of Civil Engineers* (Vol.22, No.1079, pp.167-192).

4 Cooke had a fraught partnership with Professor Charles Wheatstone, who was engaged on similar work (see box). Their story is told in the two-part work, *The electric telegraph: Was it invented by Professor Wheatstone?* By Cooke, W.F., (1857), W.H. Smith and Son, London. Further interesting research into their relationship can be seen in '*The introduction of the electric telegraph in Britain, a reappraisal of the work of Cooke and Wheatstone*' by Liffen, J. (2010), The International Journal for the History of Engineering & Technology, 80(2), pp.268-299.,

5 Cooke, W.F. (1842), '*Safeguard and Control of the Electric Telegraph'* Simpkin, Marshall, & Co., London.

THE BLOCK TELEGRAPH

Once the principle of the electric telegraph and the rule of space separation of trains had been established[6], all that remained was to find a protocol that made the most effective use of them. Initially, a simple, battery fed circuit, as devised by Cooke, was arranged between stations that showed 'Line Clear' or 'Line Blocked' on a disc fitted with an indicating needle (Figure 1).

Electrically operated, single stroke bells connecting the signal boxes were added to allow the exchange of messages. Often, the 'speaking telegraph' was installed as well. Over the years the 'speaking telegraph' was removed and an increasingly complex set of bell codes was devised. Each enquiry or action by the signalman was indicated first by a bell code, followed by the operation of the block instruments if required. The bell code received by a signalman was usually repeated back to the sender to indicate receipt and understanding. Although there was a range of variations and improvements to Cooke's basic ideas, his block telegraph principles were sound and have survived to this day

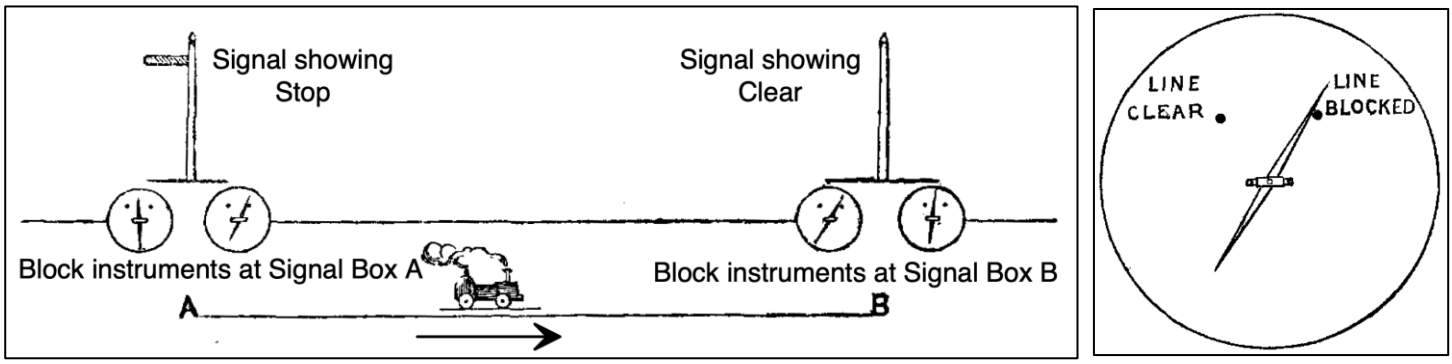

Figure 1: A two-part diagram showing the principles of Cooke's block telegraph system of 1842. Each signal box had two instruments, one connected to the box in rear and one to the box in advance for each direction. The signalman at Box A switched his instrument connected to Box B showing 'Line Blocked' as a train entered the section and this would be indicated on the disc in Box B, as shown above. He would also replace his signal to 'Danger' and maintain it in that position until he had 'Line Clear' from the man at Box B. When the signalman at Box B observed that the train had cleared his end of the section, he would switch his instrument to 'Line Clear' and this indication would be repeated on the disc at Box A to allow the Box A man to admit another train into the section. A bell circuit was provided to enable the signalmen to alert each other to the approach or clearance of trains. Note that the signals show a horizontal semaphore arm in the 'danger' position with no arm visible in the 'Clear' position. This practice survived into the late 1860s on many railways. Drawings adapted by the author from Preece (1863).

SIGNAL INDICATIONS

Early arrangements for showing instructions to train drivers were diverse, but they were usually flags or signs displayed at the lineside.

The first example of a fixed signal is recorded as a flagpole being erected in 1833 on the Liverpool & Manchester railway[7]. Each railway company adopted its own system (rectangular boards and large discs were popular) but the introduction of shared operation of lines and running powers over various routes led to moves towards standardised signals.

ON AND OFF

Railway folk refer to signals as "on" or "off". "On" means the signal is showing a 'stop' indication while "off" means it is showing a 'proceed' indication. These descriptions refer back to the very early days of railways when a signal consisted of a board on a post. If you wanted to tell the driver to wait, you showed the board on the post, facing the driver, so a signal was "on" the post. When it was OK for the driver to go, you turned the board "off" by rotating the post 90 degrees (Byles, 1910, p.15). Even today, some main line drivers still refer to signals as "boards". In some areas, like the Midlands, they are called "pegs". On the Underground, they are referred to as "sticks", perhaps due to their connection with 'stick relays'.

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[6] Byles suggested in his book '*The First Principles of Railway Signalling'*, published by The Railway Gazette, London, in 1910, that it was 1850 before the block telegraph was used but William Preece said in 1863 in a paper to the Institution of Civil Engineers 'On Railway Telegraphs, and the Application of Electricity to the Signalling and Working of Trains' that it was first tried on the Eastern Counties Railway between Norwich and Yarmouth in 1844. Byles' dedication to signalling was such that, after his death in 1952, his ashes were scattered from the West Signal box over Sydney Yard.

[7] Dawson, A. (2017), '*Working on the Victorian Railway, Life in the Early Days of Steam'*, Amberley Publishing, Stroud, UK, p.119.

These were a long time coming but eventually, following an experimental installation by Charles Gregory (later Sir) at New Cross in 1841[8], the semaphore arm became the signal of choice and a gradual (but very gradual) adoption of a common design spread over the years from the early 1840s[9] onwards.

One early feature of fixed signals[10] was that a board or disc displayed on a post indicated to a driver that he should stop his train. If the board or disc was not shown, the train could proceed. It took a while but, by the early 1860s, this latter indication was being recognised as a risky proposition. If a stop board was supposed to be displayed and was somehow unintentionally moved or absent, a driver would see a proceed signal when it actually wasn't safe to proceed. Richard Rapier in a paper to the Institution of Civil Engineers in 1874[11], provides us with an interesting illustrated view of the then current thinking (Figure 2). He wrote, "*On most British railways, the three signals "danger", "caution" and "clear" (Fig. 37), are still used at intermediate stations, and "stop" and "caution" at junctions. On some, [such] as the Great Western, Brighton, Great Eastern, Metropolitan, and South-Western, [show] only "stop" and "go on" (Fig. 38). This the Author conceives to be right, for wherever the block system is [in use] the "caution" signal means precisely the same as the "clear" signal, viz., "go on to the next signal-post;" and [an] amount of caution will afford sufficient security. There is another reason for the abolition of the caution signal …. viz., when the arm is completely down, the signal is positively absent, thus … reverting to the system (now found to be insufficient) that absence of signal means safety".* Note that Rapier quotes the Metropolitan Railway as one of the users of the two-position semaphore.

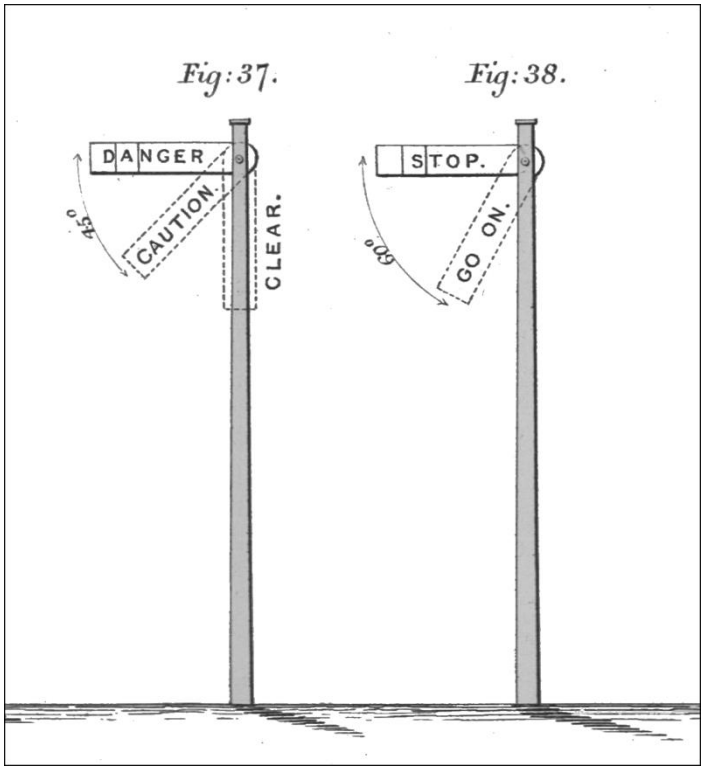

Figure 2: Two of the drawings from Rapier's 1874 paper to the Inst. of Civil Engineers showing a 3-position semaphore based on Charles Gregory's original design and a 2-position semaphore signal used later. The two-position signal became standard across most railways in the UK but the angle at lowering was 45 degrees.

Drawings modified by Author

Rapier was right to be sceptical about the idea that "absence of signal means safety". Just two years after he presented his paper, a serious accident occurred at Abbots Ripton on the Great Northern Railway when a driver proceeded under apparently clear signals and his train collided with another. It turned out that the signal arm was weighed down by snow and was almost completely invisible. Worse, the white light then used to show clear was showing as a result of the distorted signal arm. The resulting collision caused the deaths of 13 passengers, with 53 passengers and six trainmen injured. Rapier could have been forgiven if he had said, "I told you so."[12]

DEVELOPMENTS

In his 1874 paper, Rapier mentions that the shape of a caution signal was the same as a proceed signal but it indicated to the driver that he should proceed at a lower speed. This was actually a hangover of time interval system still practised on many railways at the time. It also assumed that the driver knew in

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8 Day, L and McNeil, R.I. (1996), 'Biographical Dictionary of the History of Technology' Routledge, London, p.528. Charles Hutton Gregory (1817-1898) was a civil engineer by profession and acted as consultant for a number of railway construction projects in Britain and overseas.

9 Rapier, R.C. (1874), 'On the Fixed Signals of Railways' *Minutes of the Proceedings of the Institution of Civil Engineers* (Vol.38, No.1393, pp.142-189).

10 There are two types of signals that can be presented to train drivers: A fixed, lineside signal placed near or over the track and a handsignal, now usually limited to emergencies or local, slow movements like shunting or coupling.

11 Rapier, ibid.

12 Two consequences of this accident were, first that the practice of leaving signals normally in the 'off' position was reversed and signals were subsequently normally left in the 'on' position and only cleared when required and second, the design of signal arms was modified to show a positive arm position as described by Rapier and shown in his Fig.38.

advance which type of signal he was approaching – demonstrating that learning the road before being allowed to be in charge of a train was becoming an essential requirement. It was an essential requirement and it still is today.

Rapier then relates the story of the development of the signal box and the "distant" signal. He records that a lever-worked signal was first tried on the North British Railway (NBR) at the junction of the Hawick line in Edinburgh in 1846.

Up to that time, each signal was worked individually by a 'policeman' standing at the signal post but an enterprising young policeman decided that he could do better. He was fed up with walking back and forth the 50 yards from the points at the junction he was responsible for to the protecting signal to change its indication, so he fixed a wire to the signal and ran it back to a lever in his little shelter. As a result of his enterprise, it was quickly realised that, with a group of levers put together in one place, there was an immediate saving of both time and manpower. The idea was soon adopted and the signal box was born.

A result of the development of remotely operated signals was the introduction of the 'distant'[13] signal. Increasing train speeds made observation of stop signals more difficult, particularly in bad conditions and at night and some form of early warning of a stop signal was urgently needed.

Now that a signal could be operated remotely from a signal box, it was a simple step to provide a real-time advance indication of the status of the stop signal. This became known as the 'distant' signal. It was placed far enough in rear of the stop signal to give a train the space necessary to slow down to a stop at the stop signal. The signalman now operated the stop signal and its associated distant in concert. Rapier noted that the NBR installed the first of these at St. Margaret's.

The idea soon spread and Rapier records that the Great Northern Railway provided distants as standard when it was opened in 1852[14]. The distant signal was different from the old caution signal (which just said, 'watch out and go slower') in that it had the definite purpose of indicating the status of the next stop signal. Thus, as Rapier put it, a driver seeing a distant signal showing a 'stop' indication would slow down expecting the next signal to show a stop aspect but if a distant was showing 'off', it meant the stop signal would show 'off' too and he could proceed at normal speed. Again, this principle remains true today.

One other area of development in signal indications in this period was the position of the semaphore arm. As a result of the original custom of removing the arm from sight to indicate 'clear', a semaphore arm had to be 'lowered' from its horizontal stop position. When a positive indication for 'clear' was accepted as a better indication, the arm was lowered only to a 45º angle. The expression 'the signal was lowered' for the act of changing a signal indication to 'proceed' is still used to this day, even for colour light signals.

Following the Abbots Ripton accident, the risk that an arm could be falsely lowered by the weight of snow led to an alternative solution where the arm was raised up 45º to show 'clear', rather than lowering it. This 'upper quadrant' solution was adopted by some railways as signals were replaced or new ones introduced but the Great Western Railway (and some others) stuck with the lower quadrant type and the London Underground railways adopted them, probably because of the Metropolitan's close relationship with the Great Western and its connection with their railway at Paddington.

EARLY COLOURS

Originally, railways generally adopted red as the colour for a stop or caution command and white or green for clear. Just to confuse things, some railways used green for caution. Both stop and distant signals looked the same and were painted plain red.

This became the standard in Britain until 1872 when the London Brighton & South Coast Railway cut a fishtail notch in a distant signal arm to provide a visual difference between it and a stop signal. This was later adopted by other railways but the yellow distant semaphore signal that we are familiar with in recent railway history didn't appear on main line railways until the 1920s. However, yellow arms and lights were adopted on the District Railway from 1906 after electrification and for the new tube lines built in 1905-07 as the colour for their 'repeater' signals. More on this in a future article.

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[13] At first these were known as 'auxiliary signals' but later becoming known as 'distant signals'. See Dawson (2017), p.133.

[14] The 1852 date is only correct for the short remaining London end of the route into King's Cross. Most of the main line had already been opened in stages from 1848.

INTERLOCKING

Another necessity that became increasingly obvious as experience in train operations grew was the co-ordination of point positions and the signals protecting them. Initially, signals provided at junctions were hand operated separately from point operation. Of course, errors were inevitable. There were many incidents of points being left in the wrong position for approaching trains or even occasions where the two point rails were in different positions, causing the train to be derailed. Eventually, solutions began to evolve, the first of these getting a trial at Bricklayers Arms Junction in 1843, where an arrangement of levers and stirrups was devised to prevent conflicting signals being lowered (Figure 3). It wasn't linked to points at first but it was a step in the right direction. It was devised by Charles Gregory who, as we've seen, introduced the idea of the semaphore signal[15]. Point lever interlocking with signal levers was added in a patent of 1859 by Austin Chambers in what today would be called 'a locking frame'[16].

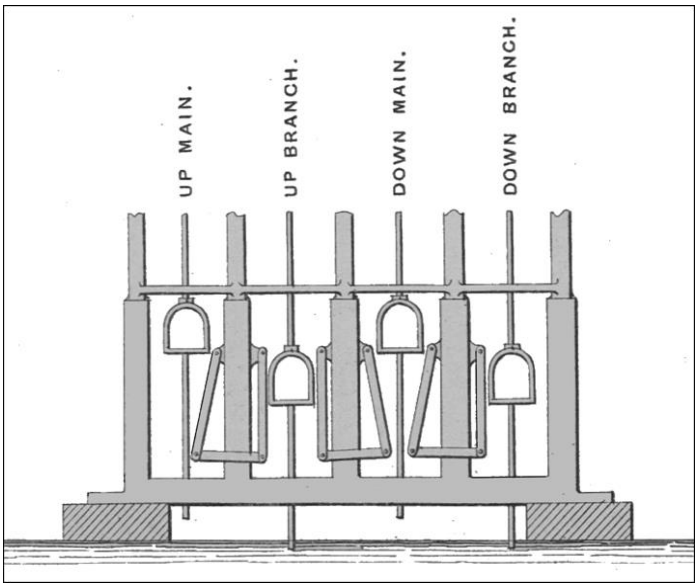

Figure 3: An early form of interlocking of signal levers in a signal frame as devised by Charles Gregory in 1843 for Bricklayers Arms Junction. Source: Rayner (1874).

Once the principle of interlocking signal and point levers to prevent conflicting routes being set up was accepted, the next development was to prevent signals being lowered unless points were both set in the right direction and locked in position. Preventing points being moved once a signal was lowered was also brought into the interlocking scheme. Various forms of it appeared from a number of different suppliers during the 1850s and 1860s and were more or less successful in service but the requirement was there and it eventually became mandatory for new railways from 1870.

THE STATE OF THE ART 1863

By the time the Metropolitan Railway opened between Bishop's Road (Paddington) and Farringdon Street (now Farringdon) in 1863, the art of signalling had evolved to a level where, on an up to date railway, semaphore arms were used to indicate both stop and caution commands to drivers, a red light meant both stop and caution, a white light meant proceed, the block telegraph was used to limit one train to once section at one time, every station had a signal box and levers were interlocked to prevent signals showing proceed over conflicting routes. Messages were passed between signal boxes by speaking telegraph or bell codes.

Point locking was under development but wasn't common. Confirmation of the location of trains was entirely visual. A train was deemed to have left a section when the signalman observed its tail lamp passing the signal protecting the entrance to the next block[17]. There was no automatic train detection so there was a considerable reliance on the discipline and alertness of signalmen to ensure the safe passage of trains through blocks and over junctions.

There were lapses from time to time, some with fatal consequences. The inspectors of the Board of Trade, the government body responsible for approving new railways and for investigating accidents, tried hard to get improvements in safety but the introduction of new technology was resisted by many railway companies, largely because of the expense, until it was enforced by law.

To be continued …

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15 Rapier, R.C. (1874), 'On the Fixed Signals of Railways' *Minutes of the Proceedings of the Institution of Civil Engineers* (Vol.38, No. 1393, pp.142-189).

16 See 'Discussion on The Fixed Signals of Railways', *Minutes of the Proceedings of the Institution of Civil Engineers* (Vol.38, pp.190-247.

17 Even today, as a passenger, I have not forgotten my very early training to observe each train as it passes to ensure everything is secure and the rear lamp is displayed properly.