White Paper

Park Signalling Limited

Virtual Lineside Signalling

Abstract

Nearly all railway signalling for manually driven trains has, since its inception, relied on the timely presentation to train drivers of appropriate images at appropriate locations. Traditionally this has involved lineside signals and bespoke, wired communications systems. Once icons of modernity, these systems now appear increasingly obsolete and expensive to maintain.

Meanwhile, the railways' own passengers and staff have grown adept at sending digital images from anywhere, to anywhere, instantly and cheaply via commercial wireless mobile picture messaging services running on their camera phones and laptops.

The paper attempts to address this recent, but historically ironic, technological disparity by first examining how signal aspects differ from wirelessly transmitted digital images, e.g. geolocation and fail-safe behaviour. It then proposes a number of technical measures to mitigate these differences such that centrally transmitted digital images displayed in the train cab can effectively function as virtual lineside signals.

It is argued that practical application of this novel technique could result in significant savings in both initial installation and ongoing maintenance cost compared to either conventional lineside signalling or current generation cab signalling systems.

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Patent applied for: WO/2010/139920.

Introduction

Railway signalling and telecommunications go back a long way. Cooke and Wheatstone were granted their electric telegraph patent in England in June 1837, just seven years after the opening of the Liverpool and Manchester Railway. A month later it was demonstrated to Robert Stephenson and two years later in July 1839 the first permanent electric telegraph in England was constructed for I. K. Brunel alongside the Great Western Railway between Paddington and West Drayton. In 1842 W. F.Cooke's pamphlet *Telegraphic Railways* contained the first description of electrically monitored 'block signalling' and later that year Charles Hutton Gregory installed the first railway semaphore signal on the London and Croydon Railway.

Ever since those early days nearly all railway signalling for manually driven trains has relied on the timely presentation to train drivers of appropriate images at appropriate locations. Traditionally this has involved lineside signals and bespoke, wired communications systems. Once icons of modernity, these systems now appear increasingly obsolete and expensive to install and maintain. Meanwhile, the railways' own passengers and staff have grown adept at sending digital images from anywhere, to anywhere, instantly and cheaply via commercial wireless mobile picture messaging services running on their camera phones and laptops. Surely railway signalling can benefit by trying to reduce this recent, but historically ironic, technological disparity.

What *is* a railway signal?

A railway signal, as its name suggests, is above all a means of communication. Its purpose is to convey to train drivers the safety related instructions of signallers. In the case of a semaphore or colour-light signal most of its meaning and function can be summarised in a simple picture of the signal head. However, this simplistically ignores its most significant attributes, namely its location and fail-safe behaviour.

Geolocation

A lineside signal is typically composed of a base, a pole and some lights or arms. However it only really is a signal once it can be considered to regulate the passage of trains past a particular location on a railway track. All lineside signals thus have an inherent identity based on their installed geographic location (geolocation) and orientation. Signal identification plates formalise this identity. The finite size and illumination power of a signal also physically limits the sighting distance and viewing locations of a given signal.

Fail-safe behaviour

Long braking distances combined with steering by the track mean that signals showing false proceed aspects are uniquely dangerous in the context of train operation since they not only increase the risk of a collision but may virtually guarantee that one occurs. Consequently considerable effort has been applied across generations of signalling equipment to prevent false signal clearance. This is embodied in the concept of fail-safe operation, whereby signalling equipment failure is categorised as 'right-side' if it results in the display of a stop aspect, either directly (red aspect) or indirectly (black aspect) and 'wrong-side' if a proceed aspect is displayed.

Picture This

Based on the widespread adoption of flat-panel displays for industrial, automotive, ATM and many other display uses, it appears reasonable to assume that a modern in-cab display is quite capable of *visually* recreating a synthetic or imaged railway signal inside a train cab. The bigger challenge, particularly in safety terms, is to try and instil geolocation and fail-safe behaviour into a display system that intrinsically has neither.

A proposed solution is summarised in Figure 1 below. It combines centralised, encrypted digital signal image generation and local, in-cab signal image display. It achieves image geolocation by locking local image decryption to the reception of lineside RFID tag or balise identities. It achieves fail-safe display via commercial-off-the-shelf (COTS) communications, processing and display systems by effectively using steganography to hide signalling content from the underlying delivery system.

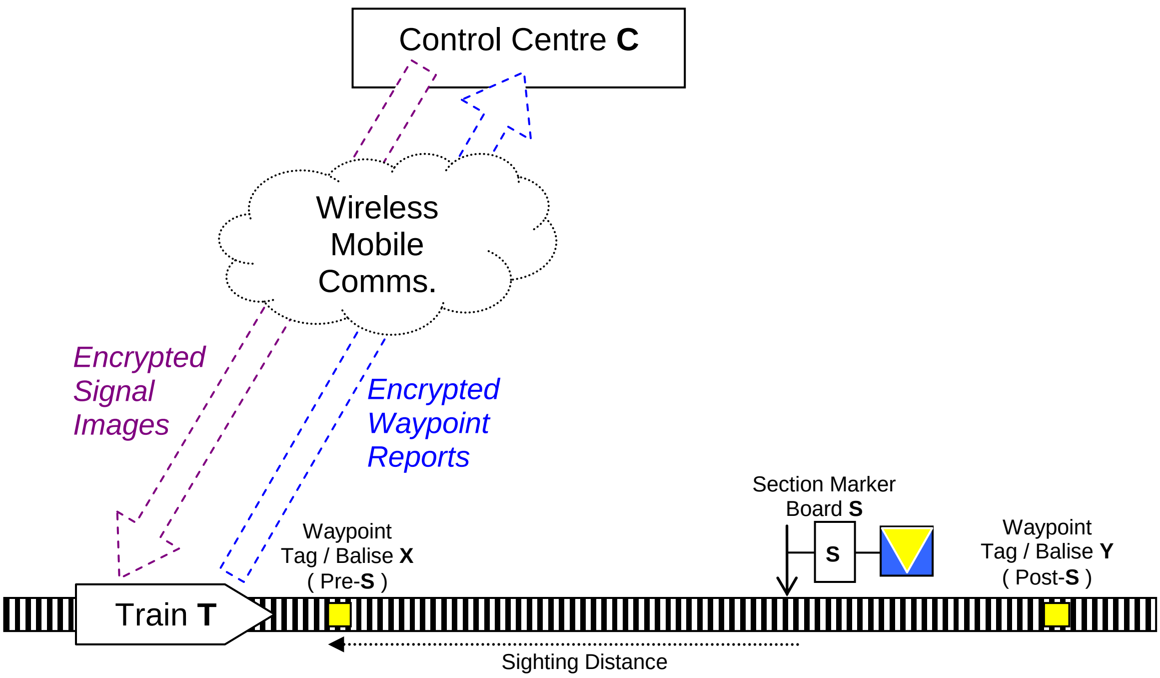


Figure 1. Virtual Lineside Signalling Communications Architecture

Need To Know

The core concept which underpins cost-effective implementation of Virtual Lineside Signalling (**VLS**) is that *the in-cab signal display system does <u>not</u> need to know anything about railway signalling*. This may seem counter-intuitive at first, but is based on the following system design rationale:

1. We are trying to generate a low-cost, in-cab, synthetic lineside signal using as little specialist equipment as possible, either trainborne or trackside;
2. By restricting our scope to supplying signal aspects to just the driver (as opposed to onboard ATO or ATP systems, etc.) only an image is required;

3. A graphical image or picture is not only very easy for the driver to interpret, it is also very difficult for a machine to interpret it or meaningfully edit it without recourse to special software (re. human versus machine cognition);
4. Although the image has to be displayed in-cab, it can be originated elsewhere (i.e. back at the control centre) so the cab system does not require the ability to locally author proceed aspect images, so image display can be fail-safe;
5. Encryption against train identity can prevent image display on the wrong train;
6. Encryption against a time code can prevent display of highly delayed images;
7. Encryption against an RFID tag or balise ID can ensure geolocation;
8. The sequence in which a railway train passes through geographic locations is determined by the track and is thus entirely predictable for a signalled route.

Putting this all together it means, in effect, that a suitably encoded, centrally generated proceed aspect image can be virtually guaranteed to appear on the right train display, at the right time and at the right place or not at all, even when using COTS trainborne equipment, provided that the control centre equipment is of sufficient integrity - which the underlying central interlocking would need to have anyway.

Graphical Security Features

A high-resolution colour digital image can obviously portray almost anything. However in the specific case of a virtual lineside signal certain graphical elements stand out as being either essential or at least very desirable. Figure 2 below shows a screenshot from our VLS demonstration system, annotated with descriptions of its salient features.

Although Figure 2 shows an image file, the most significant security features actually stem from the textual elements. This is because text, when serialized via a raster scanned bitmap file format such as PNG, contains a much higher level of redundancy than individual character codes. When combined with the additional anonymity of embedding within a larger image file the net result is that it is very difficult for a local display system to undetectably replace an embedded text string with a local one.

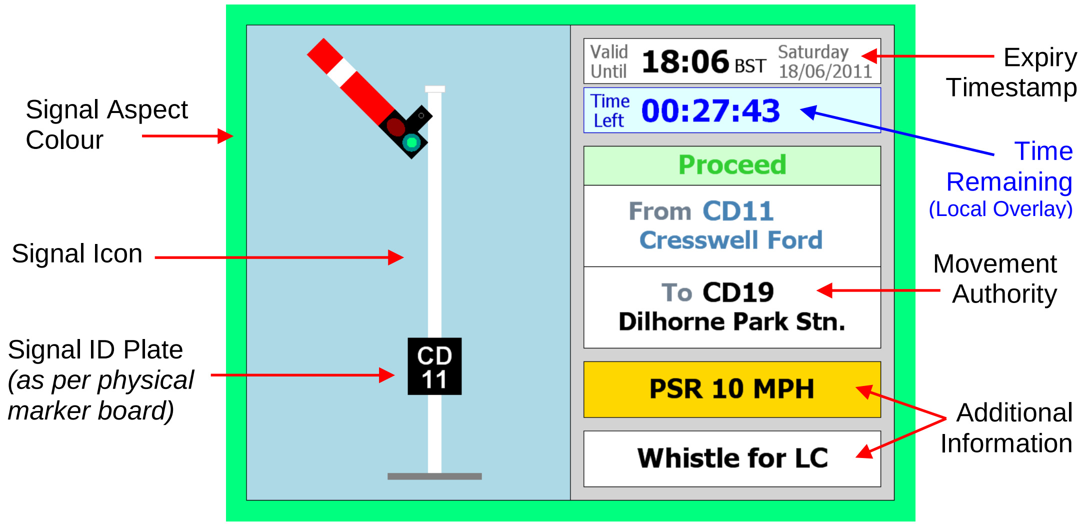


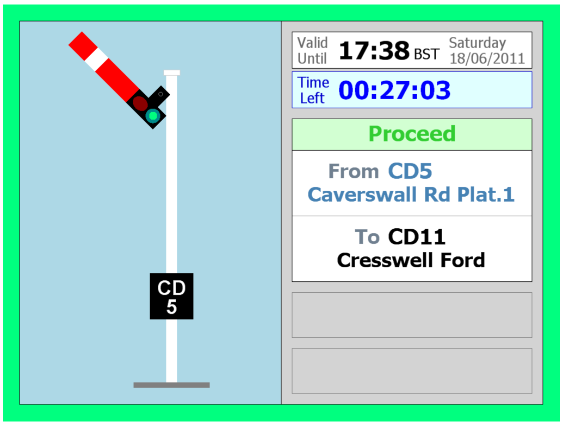
Figure 2. Virtual Lineside Signal Image (annotated)

VLS Demonstration System

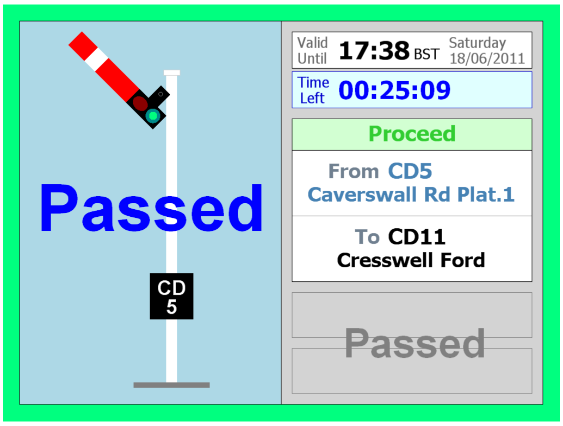
Park Signalling has developed a demonstration prototype of VLS based on a laptop PC and an RFID tag reader which is already used on the railway (TagMaster AB). Table 1 below shows a sequence of VLS images for a short route (followed by a SPAD alarm).

Table 1. A Sample VLS Image Sequence (short route followed by a SPAD)

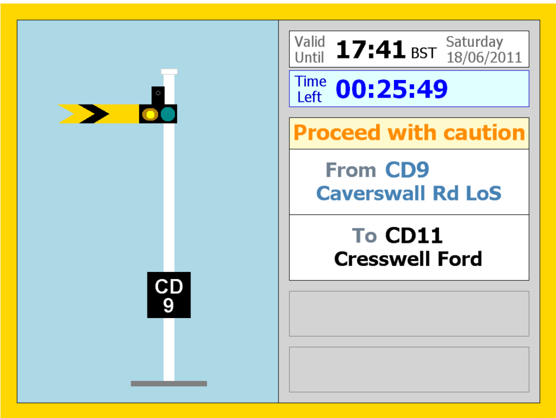
1.1 Proceed aspect at start of route



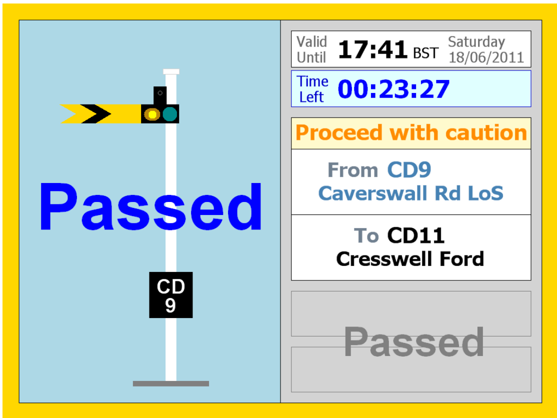
1.2 Starting signal passed



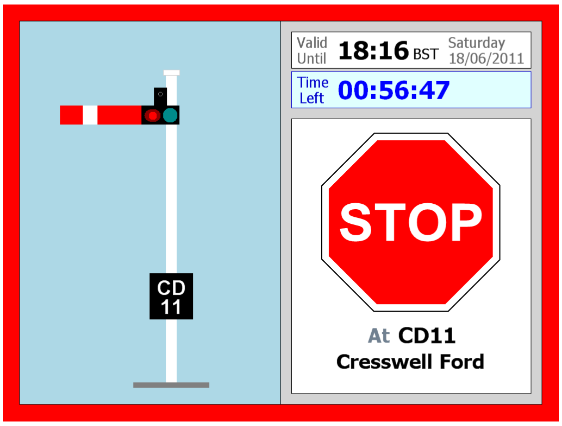
1.3 Caution signal near end of route



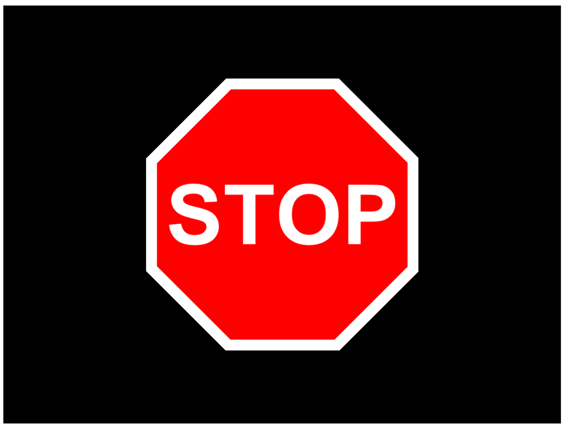
1.4 Caution (Distant) signal passed



1.5 Stop signal at end of signalled route



1.6 SPAD alarm after stop signal passed



Implementation

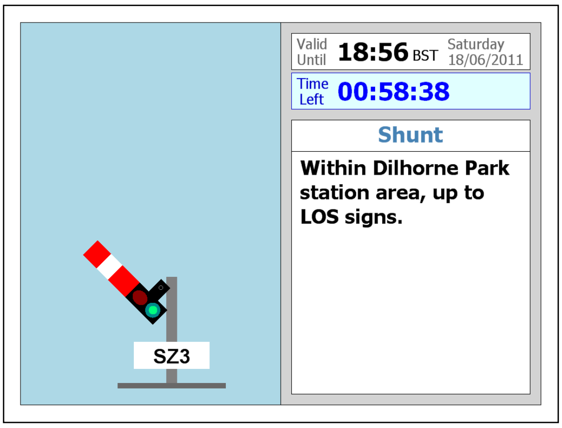
For the technically minded our current VLS demonstration consists of AES encrypted PNG images protected by HMAC signatures and transmitted via TCP/IP over GPRS. This decade's technical acronyms aside, the more important point is that VLS is based on transmitting digital images over digital wireless communications and displaying them on commodity display technology. In other words the basic architecture is hardware, software and vendor neutral and thus should be supportable for the foreseeable future.

Local Image Generation

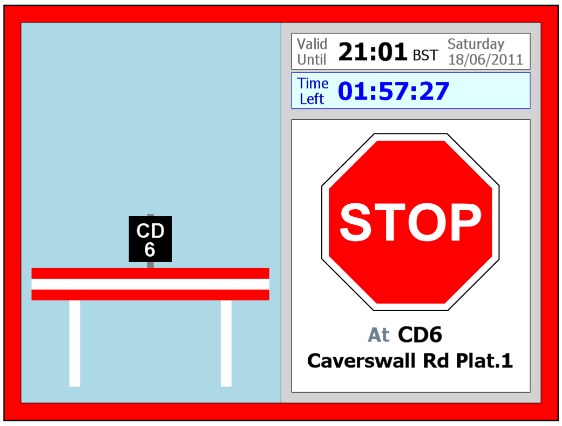
Although it is forbidden for the cab display to originate proceed aspects, there is less restriction concerning image annotation or alarm displays on the grounds that any errors or failures would not increase the risk to the train. For example, an image of signal S is cued for display by reception of the appropriate Pre-S ID at sighting distance (see Figure 1). Subsequent display of 'PASSED' on reception of the Post-S ID could be done either by transmitting and displaying a completely new image or, more cheaply, by locally annotating the original image, as shown on the right half of Table 1. Similarly, a basic (though non-vital) SPAD or rollback alarm based on unexpected tag reception can be generated locally on the grounds that failure to operate would not make things any worse and false operation would be a self-revealing right-side failure.

Table 2. A Selection of Additional VLS Images

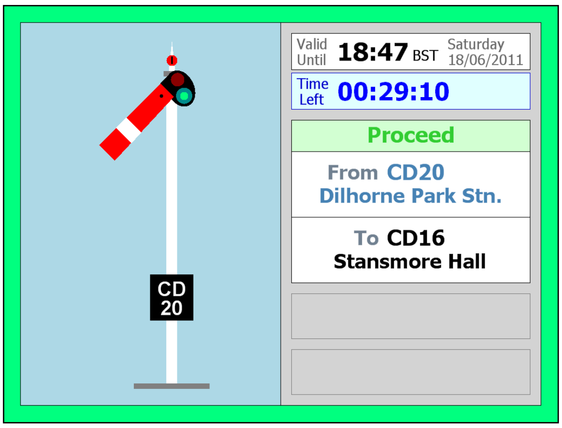
2.1 Upper quadrant shunt signal (Off)



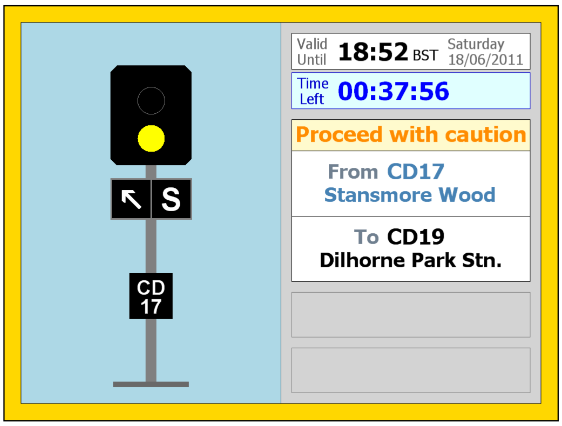
2.2 Buffer stop signal (always On)



2.3 Lower quadrant stop signal (Off)



2.4 Colour light distant signal (On) with R.I.



Further Work

At the time of writing Park Signalling has demonstrated a prototype VLS system on a heritage line in the UK and is discussing various possibilities with interested parties, including its use as an emergency replacement signalling system. However, results from the initial demonstration system alone suggest that VLS and its underlying design principles are feasible, raising interesting possibilities in both the railway signalling sphere and elsewhere, for which Park Signalling now have a filed patent application.

Complementary Systems

We have identified a number of possible trainborne subsystems which could complement VLS to form an enhanced, combined system. For example:

- Using integrated GPS/INS to provide train location either in addition to, or maybe even in place of, tag/balise based waypoints via 'virtual balises';
- Using embedded 2-D barcodes within the signal images to allow a cab-based imaging plus GPS/INS system to automatically verify displayed signal images for safety related content, e.g. liveness/expiry, location validity, aspect colour;
- Use of independent tag readers and/or GPS/INS units at each end of the train to check train integrity, i.e. the rear cab functions as an 'intelligent tail-lamp'.

Potential Cost Savings

Assuming that safety analysis, human factors analysis and trials demonstrate that VLS is practical, reliable and safe then large cost savings compared to either conventional lineside signalling or current generation cab signalling may be possible. Assuming that the train already had wireless voice and data comms. (e.g. GSM-R) then the ultimate VLS scenario, at least in the UK, would consist of:

1. Replacing the lineside signal with an unpowered section marker or stop board;
2. Replacing the trackside AWS and TPWS inductors with an RFID tag or balise;
3. Replacing the trainborne AWS and TPWS sensors with a tag or balise reader;
4. Replacing the AWS cab display with something akin to a 'digital picture frame';
5. Positive train reporting via tag/balise reports back to the control centre.

The main VLS cost savings are trackside and would stem from the avoidance of having to continually install, maintain and renew electrical power supplies, comms. hardware and many of miles of expensive cabling at remote locations in all weathers. The main trainborne advantages with VLS stem from how little additional trainborne equipment and cabling would be required to actually realise it, i.e. the small amount of VLS equipment required on each train would more than pay for itself in trackside savings.

ERTMS Regional

As things currently stand an ERTMS DMI alone costs more than we would prefer to envisage for an entire trainborne VLS system. However it should be possible in principle to use either the location reference or packet 44 data of an ETCS Eurobalise telegram to provide VLS with the same data we currently obtain from an RFID tag. Thus some future version of VLS could potentially form part of a lower cost version of ERTMS Regional, recalling that VLS can a) display anything; and b) its refresh rate primarily depends on the available transmission bandwidth from the centre and the number of distinct, predictable location references available.

Summary & Conclusion

Railway signalling is inherently based on communication and was the original 'early adopter' of nascent telecommunications technology as far back as 1839. For various often well-intentioned reasons railway signalling has become progressively slower at adopting new telecommunications technology to the point where it has effectively been overtaken by the railways' own passengers and staff. For example, train drivers now routinely use their mobile phones in preference to old signal post telephones and cab radios while their passengers send voice, text and picture messages around the world.

Given that nearly all railway signalling for manually driven trains relies on the timely presentation to train drivers of appropriate images at appropriate locations it appears worthwhile to try and virtualise lineside signals onto in-cab displays. The approach presented here involves the control centre sending digital images of signals out to the train via wireless mobile communications. The images are encrypted using keys which depend on a number of factors including the train identity, the time and date the image was sent and the identity number of a trackside RFID tag at the physical location of the lineside signal being virtualised.

The net effect is that a suitably encoded, centrally generated signal aspect image can be virtually guaranteed to appear on the right train display, at the right time and at the right place or not at all, even when using COTS trainborne equipment, provided that the originating control centre equipment is of sufficient integrity.

Assuming that safety analysis, human factors analysis and trials demonstrate that VLS is practical, reliable and safe then large cost savings compared to either conventional lineside signalling or current generation cab signalling may be technically possible.

Author Ben Clements BSc(Hons), MSc, CEng, MIET.

Ben is a chartered engineer who has worked in the railway signalling industry since 1985. Relevant career highlights include work on:

- ATO programming and manually driving trains on the initial Docklands Light Railway;
- Formal verification of a CBTC cab-signalling system for ALSTOM, Paris, 1994-96;
- ALSTOM's 2oo3 safe computing platform, based in Manchester, London & Paris.

Ben has been Research Director of Park Signalling Limited since 2002.

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