RAIB
Rail Accident Investigation Branch

Rail Accident Report

Derailment of a tram at East Croydon 17 February 2012

Report 04/2013
March 2013

This investigation was carried out in accordance with:

- the Railway Safety Directive 2004/49/EC;
- the Railways and Transport Safety Act 2003; and
- the Railways (Accident Investigation and Reporting) Regulations 2005.

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Derailment of a tram at East Croydon
17 February 2012

Contents

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Summary

On Friday 17 February 2012 at about 06:23 hrs, a westbound tram derailed after passing over facing points as it approached the platform at East Croydon. The tram was running one minute behind the tram ahead, and was routed left to follow it towards platform 3. As the tram travelled forwards at low speed, the points moved under its leading bogie, forcing its centre and rear bogies right towards platform 2. The centre bogie derailed as the routes diverged. Approximately 100 passengers were detrained close to the platform. There were no reported injuries.

The main cause of this accident was that a track circuit failed to respond to an approaching tram and lock the points to prevent movement. The track circuit was not correctly adjusted and the rail head may have been contaminated with silt. The RAIB also found that system integration was inadequate.

The RAIB has made three recommendations to London Tramlink that focus on operational and signalling arrangements, the control of silt and rail head contamination, and track circuit settings.

Introduction

1 The purpose of a Rail Accident Investigation Branch (RAIB) investigation is to improve railway safety by preventing future railway accidents or by mitigating their consequences. It is not the purpose of such an investigation to establish blame or liability.

2 Accordingly, it is inappropriate that RAIB reports should be used to assign fault or blame, or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

3 The descriptions of equipment and events contained in this report are based on site measurements, site and vehicle testing, witness interviews, maintenance records, industry reports and CCTV evidence and data recorded by the signal control system and tram number 2538.

4 Dimensions are measured from the normal stopping position for westbound trams at platform 3 at East Croydon tram stop unless noted otherwise. References to right-hand and left-hand are in the direction of travel for a westbound tram.

5 The report contains abbreviations and technical terms (shown in italics the first time they appear in the report). These are explained in appendices A and B.

Background

6 The London Tramlink system connects Croydon town centre in south London with Wimbledon to the west and Beckenham Junction, Elmers End and New Addington to the east. The system, serving 38 tram stops, opened to passengers in May 2000.

7 Trams approaching East Croydon tram stop from the east use a street-running section of double track. After crossing Cherry Orchard Road, approximately 150 metres before East Croydon tram stop, trams are segregated from road traffic although the surface is still paved. The tramway crosses Billinton Hill, an access road (also known as Post Office Road) 90 metres before the tram stop (figure 2).

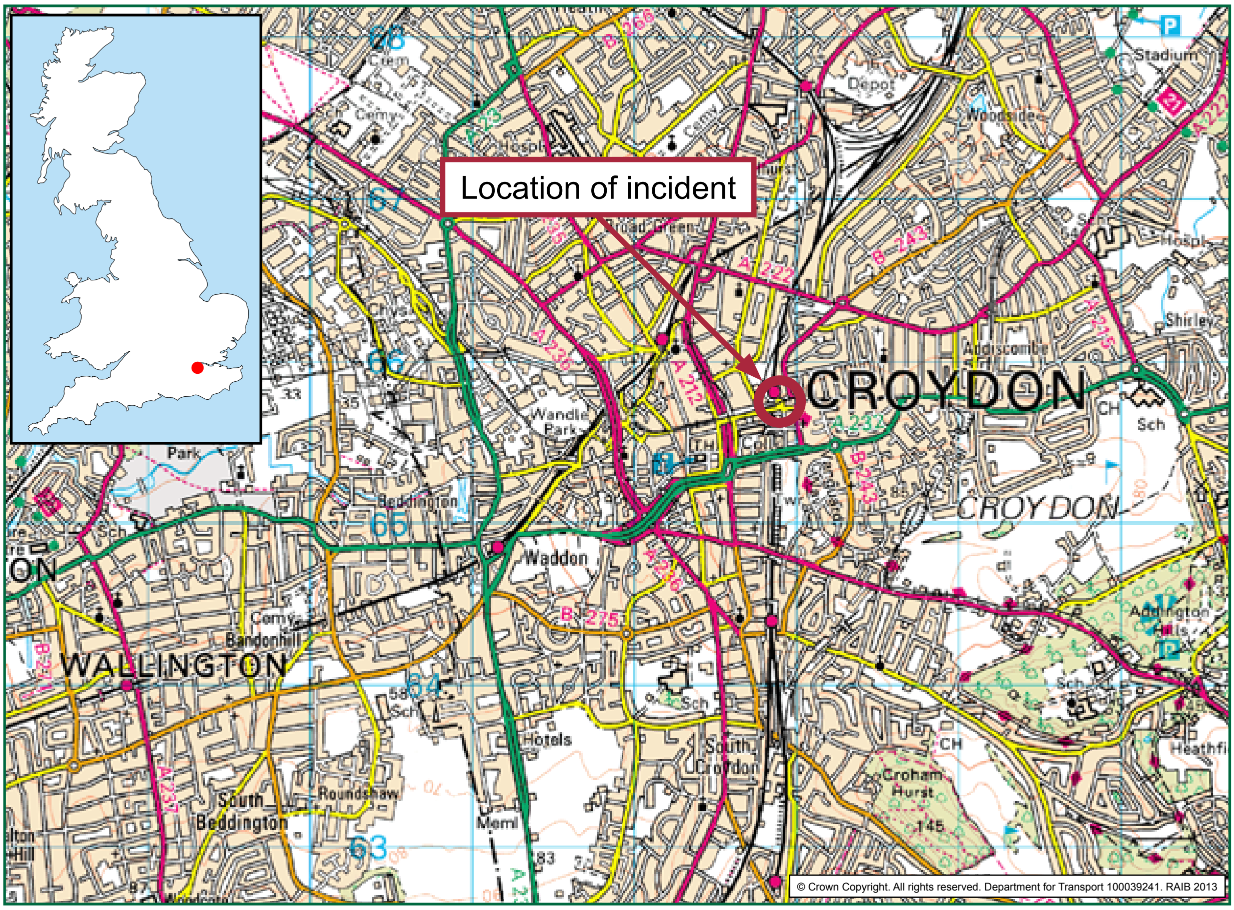

Figure 1: Extract from Ordnance Survey map showing location of accident

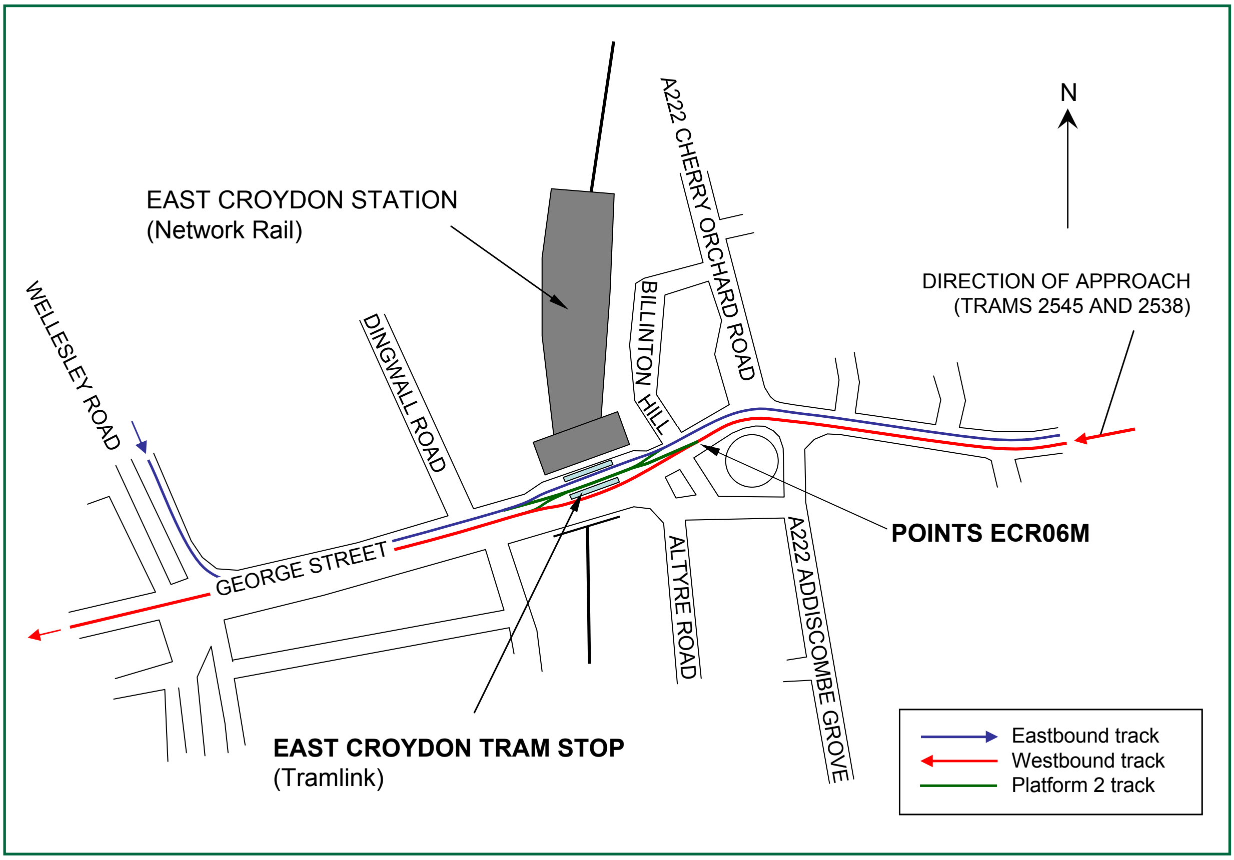

Figure 2: Map of East Croydon tram stop

8 The two running lines divide to serve three platforms at East Croydon. Platform 1 serves eastbound trams, platform 3 westbound trams, and platform 2 serves trams travelling in either direction depending on the operating mode set by the tram control room. At the time of the accident, East Croydon was set to operate in mode B, meaning that although westbound trams would normally be routed into platform 3, the signalling system would route a tram to platform 2 if it approached when platform 3 was already occupied.

9 The westbound line divides at motorised *facing points* ECR06M, located 98 metres from the tram stop and east of Billinton Hill road crossing. The position of points ECR06M (ie whether the route is set to the left or the right) is displayed to an approaching tram by a *points position indicator* (PPI). This is mounted on the same post as the signal that authorises tram movements across Billinton Hill (figure 3). After these points the routes run parallel before diverging near the platforms. Until August 2009, points ECR06M were located west of the road crossing, but they were repositioned during track remodelling to improve reliability. Trams are limited to a maximum speed of 25 km/h (15 mph) in the vicinity of points ECR06M.

Figure 3: Billinton Hill (Post Office Road) crossing showing points ECR06M, the traffic signal (showing a horizontal row of lights indicating 'stop') and PPI (indicating a route to the right)

10 Both trams in the vicinity of the accident were of the CR4000 type, built by Bombardier Transportation (Bombardier), and were brought into service when the tramway opened in 2000. The vehicles have three bogies and comprise two cars joined by an articulation unit. Motor bogies at each end of the vehicle have solid axles, whereas the central trailer bogie (located beneath the articulation unit) has *stub axles* to provide a low-floor interior (figure 4).

11 A 750V DC overhead supply provides power to trams via a roof mounted pantograph.

12 A private consortium built Tramlink's infrastructure, and initially operated the system under a concession. In June 2008, Transport for London bought out the concession and set up a new division, London Tramlink, to operate and maintain the infrastructure.

13 Hanning and Kahl (H&K) manufactured and installed points ECR06M and its control system prior to Tramlink opening in 2000.

14 Trams are operated by Tram Operations Ltd (TOL), a division of First Group plc, and have been maintained since new by Bombardier. At the time of the derailment, Bombardier were under contract to TOL. On 1 April 2012, the contract was transferred to London Tramlink. This change played no part in the cause of the derailment.

Figure 4: A CR4000 tram

The accident

15 The accident occurred at about 06:23 hrs, just before dawn on Friday 17 February 2012. The weather was dry following overnight rain. Tram 2538 was approaching East Croydon tram stop in the westbound direction and, after observing that the PPI for points ECR06M was displaying a left-hand (platform 3) indication, the driver applied power to take the tram over the points. The leading bogie of tram 2538 was directed towards platform 3, but the points moved as this bogie was passing over and caused the right-hand *switch rail* to make contact with the trailing right-hand wheel, damaging the switch rail *tip* (figure 5). As a consequence of the points moving, the centre and trailing bogies were directed right towards the other platform.

Figure 5: Damage to right-hand switch rail tip (points ECR06M)

16 Tram 2538 was travelling at 12 km/h (7.5 mph) when the centre bogie derailed to the left. This occurred 34 metres beyond the switch rail tip when the vehicle's articulation was unable to accommodate the diverging routes taken by the leading and centre bogies. The tram driver sensed an unusual movement and applied the vehicle's emergency brake. The tram came to a stop after travelling for a further 4 metres in a derailed condition (figures 6 and 7).

17 There were no injuries among approximately 100 passengers on the tram, some of whom were standing. Passengers left the tram under the guidance of the driver via the leading passenger door which had stopped close to East Croydon tram stop.

Figure 6: Front view of tram 2538 following derailment

Figure 7: Rear view of tram 2538 following derailment

18 The derailment caused minor damage to tram 2538's wheels, the road surface and points ECR06M.

19 Following an examination of the derailed tram and testing of the infrastructure by London Tramlink and the RAIB, tram 2538 was removed from site and the line was reopened in time for the evening rush-hour service. Points ECR06M were secured to direct westbound services into platform 3 while London Tramlink undertook a detailed review of the signalling arrangements at East Croydon. This work remains ongoing at the time of publication of this report.

Stored request to move the points

20 Tramlink's *programmable logic controller* (PLC) signalling system at East Croydon first detects an approaching westbound tram when it passes over *induction loop* COR07. This loop is located in the road surface west of Cherry Orchard Road crossing, 35 metres before ECR06M points and 133 metres from the tram stop. The system next detects the tram, when it arrives in either platform 3 or platform 2, by induction loops located at the west end of the platforms (ECR10 and ECR09 respectively, figure 8).

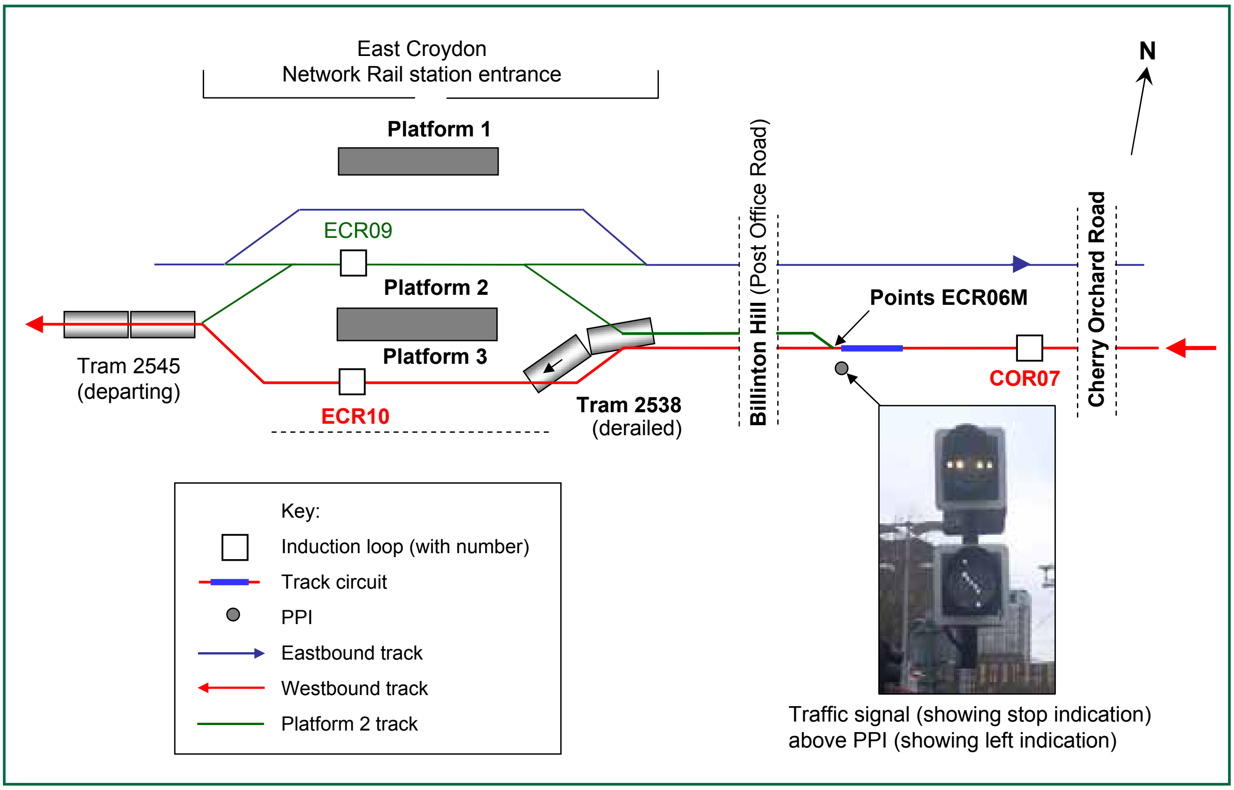

Figure 8: Schematic diagram of part of the East Croydon signalling system and location of tram 2538 following derailment

21 The signalling system controls points ECR06M by sending a voltage pulse to the *point controller* requesting it to direct trams left towards platform 3, or right towards platform 2. The request is accepted by the point controller unless the *track circuit* or *mass detector* has responded to the presence of a tram in the immediate vicinity (paragraph 37). In this case, the point controller will have locked the points to prevent movement and the request is ignored.

22 In operating mode B (paragraph 8), if a second tram is detected by loop COR07 before the first tram has reached loop ECR10 (or ECR09), the signalling system will store the request to the point controller. The stored request is only released when the first tram is detected by loop ECR10 (or ECR09).

23 On 17 February, tram 2545 approached East Croydon travelling west, followed by tram 2538 running one minute behind it. The signalling system detected tram 2545 as it passed over loop COR07 at 06:22:14 hrs and routed it left at points ECR06M towards Platform 3. Points ECR06M were already set in this direction after the previous tram and did not have to move.

24 Tram 2545 stopped in platform 3, but short of loop ECR10, so its arrival in the platform was undetected by the signalling system while the tram was stationary.

25 At 06:23:13 hrs, the signalling system detected tram 2538 passing over loop COR07. Since tram 2545 had been routed into platform 3, the signalling system was programmed to request points ECR06M to change and direct tram 2538 into platform 2. However, because tram 2545 had not yet reached loop ECR10, the request to change the points was stored in the signalling system.

26 If tram 2545 had stopped on loop ECR10, the stored request would have been released, and points ECR06M would have moved to direct tram 2538 towards platform 2, before tram 2538 reached the points.

27 At 06:23:28 hrs (ie 15 seconds later), tram 2545, which had completed its tram stop duties and was moving away from the platform, was detected by loop ECR10. This provided the signalling system with confirmation that tram 2545 had arrived at platform 3 (even though it was now departing), and caused the signalling system to release the stored request for points ECR06M to move and direct tram 2538 towards platform 2. The points were still moving in response to this request when tram 2538 reached them two seconds after the request was released (refer to paragraph 42).

28 TOL's operating instructions for East Croydon require a following tram to wait at the PPI until the PPI shows a route into an unoccupied platform (ie an empty platform or a platform where the previous tram has started to move away). This means that, provided the preceding tram stops on the appropriate loop (ECR10 in this instance), stored requests will be actioned before the driver of a following tram passes the PPI.

29 As tram 2538 approached the PPI, its driver could see tram 2545 moving away from the platform ahead. Therefore, TOL's operating instructions allowed him to pass the PPI and proceed towards platform 3.

30 Tramlink drivers are taught to stop on loops. They are told this improves operational efficiency because it means that they can request traffic signals ahead to prepare to change in their favour before the tram starts moving. Drivers are not told that this is a safety requirement. There are no signs or markers to indicate the position of the loops in platforms 2 or 3 at East Croydon where the track is paved. Drivers are trained to check, once stopped, that the tram is in the correct place by looking for an icon which appears on their cab display when the tram reaches a loop. TOL managers are not concerned if they occasionally stop before the loop.

31 Signalling records show that the same tram driver also stopped short of loop ECR10 when driving tram 2545 from the other cab 45 minutes before the accident during an earlier journey. It is not known whether this was habitual behaviour, but TOL's driver monitoring programme had not identified him as a poor driver.

Identification of the immediate cause[1]

32 **Tram 2538 derailed because points ECR06M moved beneath the vehicle, setting the centre and rear of the vehicle on a diverging route.**

33 An examination of damage to the switch tip rail, and an analysis of the tram's data recorder, local data loggers and CCTV images, shows that ECR06M points moved as the leading bogie of tram 2538 was passing over. As a consequence the leading bogie was directed towards platform 3, and the centre and trailing bogies were directed right towards platform 2 (figure 8). The derailment occurred another 34 metres beyond the points when the vehicle's articulation was unable to accommodate the diverging routes taken by the leading and centre bogies.

34 The factors that led to this outcome are described in the following sections.

Identification of causal factors[2]

Track circuit operation

35 **The track circuit which locks points ECR06M did not respond to tram 2538, and consequently the points remained free to move while the tram was passing over them. This was a causal factor.**

36 London Tramlink staff maintain points ECR06M. It is one of nine sets of motorised facing points on the Tramlink network. Each point controller (paragraph 21) is self-contained, only interfacing with the signalling system to the extent that it receives requests from the signalling system for the points to be changed.

37 The point controller for each set of motorised facing points incorporates a track circuit and a mass detector. These are intended to work together to lock the points to prevent movement when a tram is approaching or running over the points (figure 9).

[1] The condition, event or behaviour that directly resulted in the occurrence.

[2] Any condition, event or behaviour that was necessary for the occurrence. Avoiding or eliminating any one of these factors would have prevented it happening.

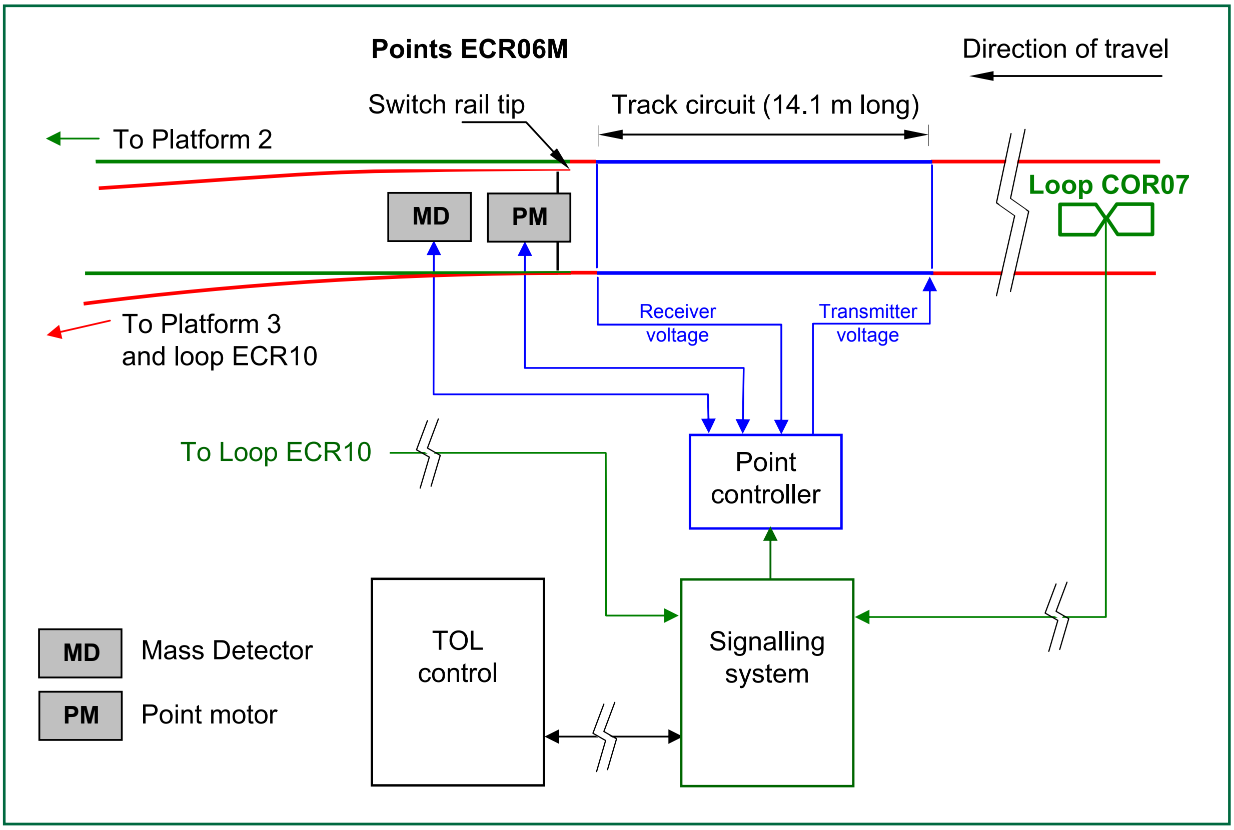

Figure 9: Schematic diagram of the point control system

38 A track circuit operates by passing a small electrical current through a circuit which includes both running rails. A track circuit responds to the presence of a tram by detecting the effect of the short circuit formed between the rails by a tram's wheels and axles. The resistance of a short circuit applied from one rail to the other is described in this report as the rail to rail resistance[3]. During installation and maintenance work, this resistance is measured by test equipment connected directly to the rails (figure 10). However, in normal operation, the rail to rail resistance comprises two components:

a. the electrical resistance of the path from one tram wheel tyre to the other (the *wheel tyre to wheel tyre resistance*); and

b. the electrical resistance of any contamination between the wheel tyre and rail head.

39 The point controller is intended to lock the points when the track circuit first responds to the presence of a tram. The point controller also then switches on the mass detector located 2 metres after the switch rail tips. The mass detector, which uses electrical induction to detect the presence of metal objects passing over it, is inactive at other times to prevent false detection (eg of other road vehicles). The points are intended to remain locked until first the track circuit, and then the mass detector, have detected, in sequence, that the tram is no longer present.

[3] This rail to rail resistance does not include the effects of any current flowing through the ground.

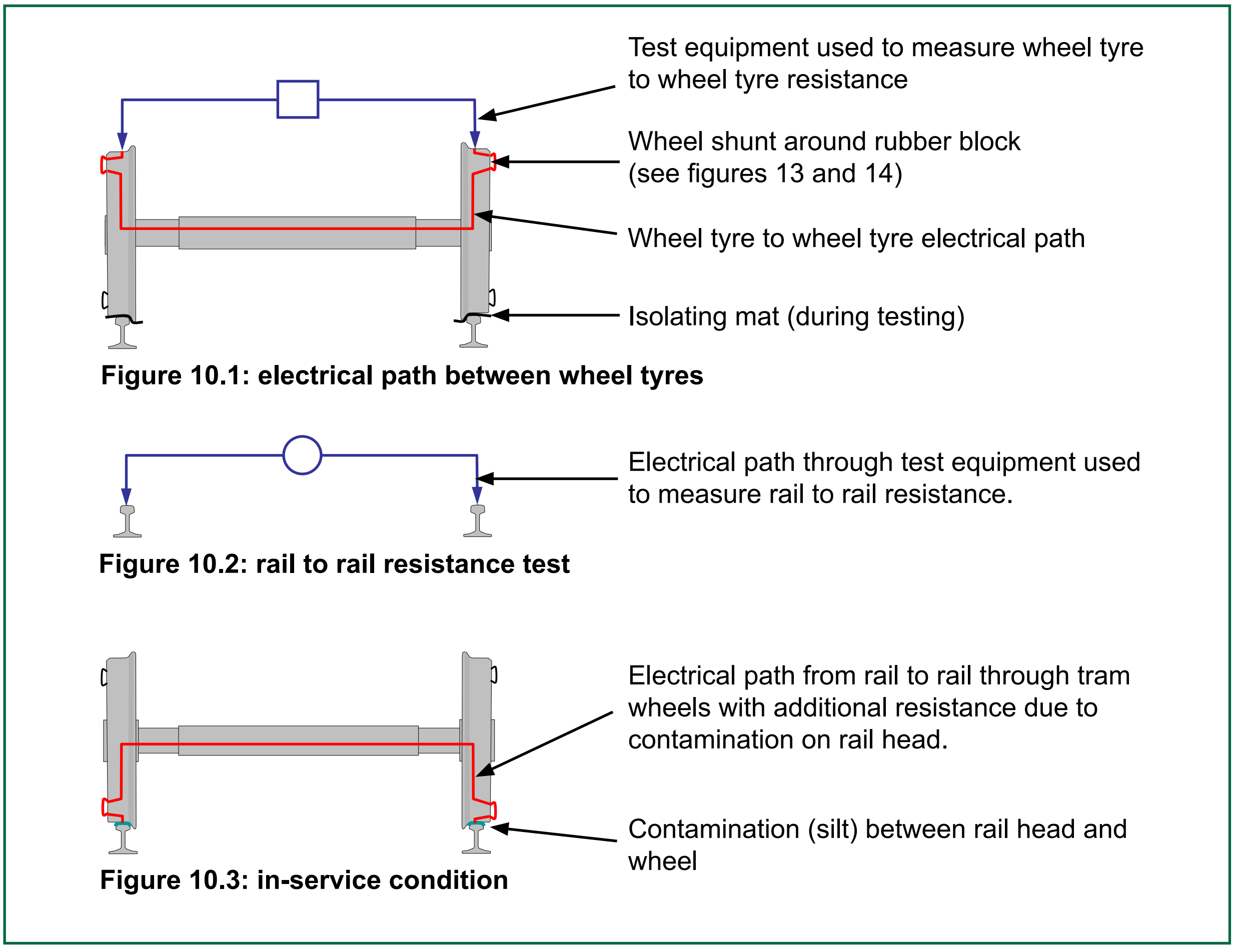

Figure 10: Diagram of electrical paths affecting operation of track circuit

40 Information provided by H&K shows that the time taken for the point controller to process a request to move the points and then for the points to move to a new position can be up to 3.5 seconds. This is consistent with RAIB observations during site testing, and the RAIB has found no evidence of any malfunction of the points that could have caused any increase in the maximum movement time quoted by H&K. This means that had a request been sent to the points just before tram 2538 entered the track circuit they would have reached their new position at least 6.5 seconds before the tram arrived at the switch rail tip.

41 An analysis of the tram's data recorder, local data loggers and CCTV images shows that the points were actually requested to move seven seconds after tram 2538 entered the track circuit (figure 11) and while it was still occupying it. Had the track circuit responded to the tram's presence the request for the movement would still have been received but the points would not have moved (paragraph 39). Since it is known that the points did move in response to the request, and testing has revealed no other malfunction of the signalling equipment, it is apparent that the track circuit did not correctly respond to the presence of tram 2538.

42 At the moment that the points were requested to move, tram 2538 was only about 3 metres, and 2 seconds, from the point tips. The points were still moving as the leading bogie passed over the switch rail tip (figure 11).

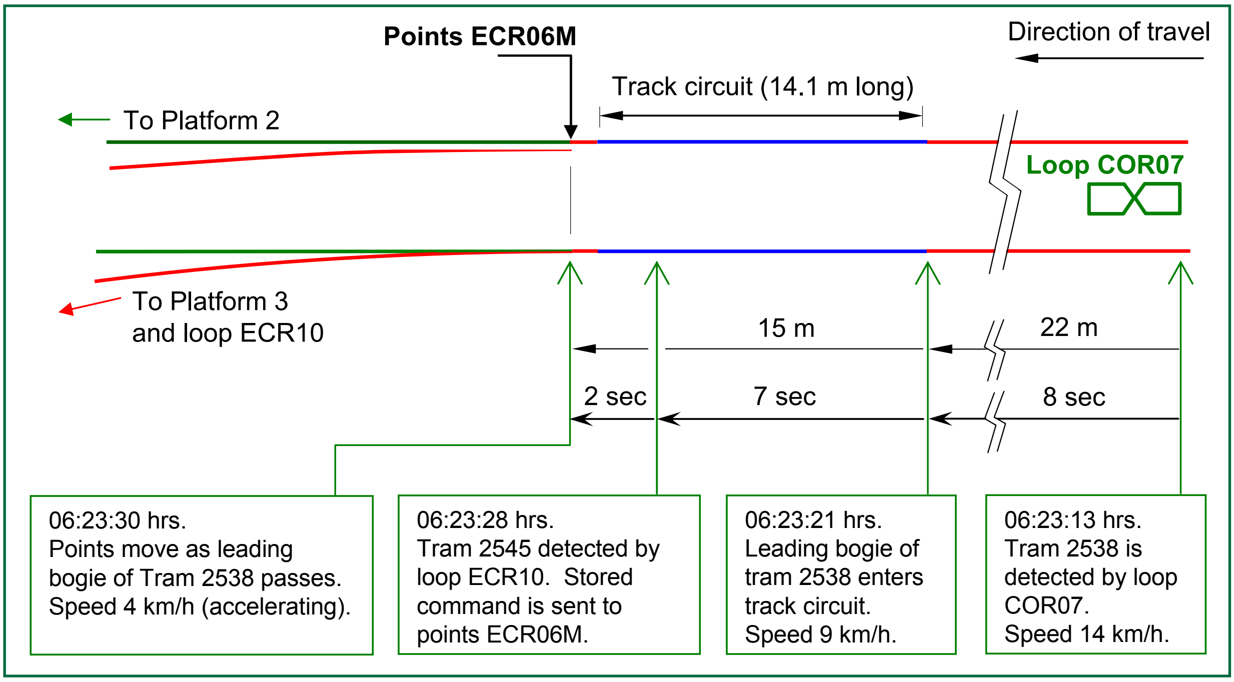

Figure 11: Diagram showing calculated position of tram 2538

43 Post-accident testing found that:

- A request from the signalling system would not cause the point controller to instruct the points to move when the track circuit was occupied.
- There was no evidence of any intermittent faults.
- The track circuit only just responded to a test tram (tram 2537). The resistance of the short circuit created by a tram is shown by the number of indicator lights illuminated on a bank of 16 lights on the point controller. A greater number of lights indicates a lower rail to rail resistance. At least 12 lights must be illuminated for the point controller to lock the points and this was all that was achieved by the test tram. This suggests that the point controller would not have locked the points if the resistance between wheel tyres on the leading bogie of the test tram had been slightly higher.
- It is possible that the track circuit responded to the test tram and not the incident tram because the wheel tyre to wheel tyre resistances of the test tram leading bogie (0.0004 ohms for each axle, table 1) were lower than the corresponding resistances on the accident tram (0.021 ohms[4] and 0.023 ohms) (figure 10).

Track circuit sensitivity

44 The track circuit voltage was not adjusted in accordance with the manufacturer's operating instructions. This was a probable causal factor.

45 The maximum rail to rail resistance which will cause the track circuit to respond to a tram is varied by making adjustments to the track circuit's *transmitter voltage*. The effect of this change is assessed by measuring the *receiver voltage* (figure 9).

[4] Wheel tyre to wheel tyre resistance values given in this report (table 1) supersede those given in the Urgent Safety Advice issued by the RAIB on 01 March 2012 (see appendix C) as they have been obtained using more accurate testing equipment.

46 H&K's operating instructions state that the track circuit should be adjusted so that it responds to the presence of a tram when the rail to rail resistance is up to 0.3 ohms[5]. This value is intended to achieve an appropriate balance between operational reliability and safety. A lower value would reduce the risk of a false response causing an unintended locking of the points by (for example) electrical current flowing through damp ground between the rails. However, a lower value would also increase the likelihood of the points remaining unlocked because a relatively high resistance on the electrical path through the tram axle meant that the track circuit did not respond to the tram.

47 H&K's commissioning records for points ECR06M indicate that the track circuit receiver voltage was set at 5.0 volts when the points were re-commissioned in September 2009 after track remodelling (paragraph 9). This setting was based on the commissioning engineer's experience of what worked in practice to prevent points being locked unintentionally. H&K's commissioning documents did not require any test resistance to be applied between the running rails to determine whether the track circuit responded as specified, and H&K has confirmed that this check was not made.

48 London Tramlink staff started recording the track circuit receiver voltages in September 2011 as part of an initiative to improve their understanding of how the equipment was operating. These records indicate that the receiver voltage for the track circuit at points ECR06M was at 5.2 volts when first tested, and that it remained at about this level until after the accident when it was recorded at 5.24 volts. It is not known how the receiver voltage was increased from 5.0 volts, as set by H&K, to 5.24 volts at the time of the derailment, but it is possible that this was the result of adjustments made by Tramlink maintenance staff when undertaking other tasks or changes in circuit resistance due to environmental changes.

49 London Tramlink staff did not have access to equipment for measuring the rail to rail resistance required to make the track circuit respond (figure 10). There was no information in any routine maintenance instructions of what the receiver voltage should be, or what the effects of a variation in this voltage would be.

50 After the accident, testing of the incident track circuit established that a receiver voltage reading of 5.22 volts (approximately equal to the voltage at the time of the accident) meant that the maximum rail to rail resistance causing the track circuit to respond was between 0.1 ohms and 0.2 ohms[6]. The operating instructions (paragraph 46) required the track circuit to respond to a rail to rail resistance of up to 0.3 ohms. Testing also found that the track circuit had to be adjusted until the receiver voltage was 4.5 volts before the track circuit would respond when a rail to rail resistance of 0.3 ohms was applied. This meant that the track circuit was not compliant with H&K's operating instructions when set up by H&K's engineer in 2009 with a receiver voltage of 5.0 volts.

[5] Often referred to as the drop shunt value.

[6] Standard track circuit test equipment varies resistance in steps of 0.1 ohms.

51 The track circuit is intended to respond to the leading bogie of a tram and cause the points to lock. The combined effect of both axles meant that the leading bogie of the incident tram provided a wheel tyre to wheel tyre resistance of about 0.01 ohms. If the track circuit had been set up with the specified rail to rail resistance of 0.3 ohms, there would have been a 0.29 ohm allowance for factors such as contamination between the wheels and rails and contamination on electrical connections in the track circuit. As the track circuit had a rail to rail resistance of between 0.1 ohm and 0.2 ohms set up at the time of the accident, the allowance for any contamination was reduced to between 0.09 ohms and 0.19 ohms.

52 Although the risk factors may have been present since 2009, the accident occurred because of a combination of circumstances: the stopping position of the leading tram, the position of the following tram when the signalling system requested the points to move, and the presence of contamination on the rail head and the higher resistance of the leading bogie axles.

Contamination by silt

53 The track circuit performance was probably affected by contamination on the rail head.

54 Although a post-accident inspection by the RAIB did not identify any unusual contamination on the track circuit rail head, some silt contamination was seen. It is possible that this was sufficient to prevent the track circuit, as set up at the time of the accident, from responding to the presence of tram 2538.

55 It is possible that some of the silt seen on the rail head had come from an accumulation of silt seen on the roadway near Cherry Orchard Road crossing during the RAIB's inspection (figure 12). It is probable that this silt had accumulated since the area was swept mechanically one week before the derailment as part of the routine fortnightly mechanical sweeping of embedded track in Croydon town centre. Drainage works were undertaken in 2009 which had reduced, but did not eliminate, the accumulation of silt near Cherry Orchard Road.

Wheel tyre to wheel tyre resistance

56 Tram 2538 had a relatively high wheel tyre to wheel tyre resistance.

57 All axles on the CR4000 tram have *resilient wheels* with braided copper bonds (*wheel shunts*) on each wheel providing electrical continuity between the wheel hub and tyre (figures 13 and 14). Bombardier's maintenance specification for the CR4000 fleet states that wheel tyre to wheel tyre resistance should not exceed 0.01 ohms on a new bogie, or rise above 0.1 ohms in service. The wheel shunts are designed to provide an electrical path for traction current to return to the rails, and Bombardier stated that the requirement for the trams to operate track circuits was not specified when the trams were designed. At the time of the derailment, Bombardier's maintenance staff remained unaware that the wheel shunts performed both roles.

Figure 12: Silt on paved surface west of Cherry Orchard Road crossing on 17 February 2012

Figure 13: Leading bogie of tram 2538 showing wheel shunt

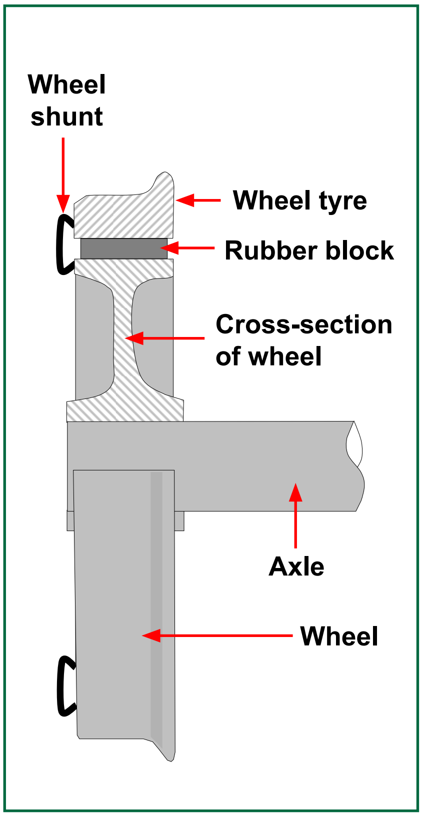

Figure 14: Part-section of wheel

58 The wheel tyre to wheel tyre resistance values for the leading bogie of tram 2538, tested in March 2012, and the remainder of the CR4000 fleet, tested in July 2012, are given in table 1. These results show that, although tram 2538's leading bogie conformed to Bombardier's own maintenance specification for in-service wheel tyre to wheel tyre resistance, its resistance was greater than the rest of the Croydon fleet by a factor of at least three. No explanation for this has been found by the RAIB, Bombardier or London Tramlink. The March 2012 and July 2012 testing, coupled with post-accident testing, shows that, although the track circuit did not respond to the incident tram, it would possibly have responded to other trams in the Croydon fleet at the time of the accident.

Subject	**Wheel tyre to wheel tyre resistance (ohms)**	
	Axle 1	**Axle 2**
Bombardier specification (in service, maximum – paragraph 57)	0.1	0.1
Incident Tram 2538 (bogie M033)	0.021	0.023
Test tram 2537 (bogie M024)	0.0004	0.0004
Highest value for rest of fleet	0.0009	0.0072
Lowest value for rest of fleet	0.0002	0.0002
Factor difference between 2538 and highest value for rest of fleet	x 23	x 3.2

Table 1: Table of wheel tyre to wheel tyre resistance values for CR4000 tram motor bogies

Modification to the standard point controller design

59 **A non-standard point controller installation meant that protection against points moving under trams relied entirely on the correct response of the track circuit. This was a causal factor.**

60 The standard H&K point controller was designed to be part of a system in which points are moved (if necessary) and then locked immediately after a tram is detected on the approach to the points. The locking of the points caused by occupation of the track circuit by a tram would then provide a supplementary means of ensuring that the points were locked while the tram passed over them. For unlocking, refer to paragraph 39.

61 If this standard design had been installed at East Croydon, the points controller would, when a tram was detected by loop COR07, have moved the points immediately if necessary and then locked them. This feature was deliberately not installed at points ECR06M as it would prevent stored requests from being actioned in the time between the tram passing over COR07 loop and reaching the start of the 14.1 metre long track circuit, a distance of 22 metres (figures 8 and 10). H&K has stated that the requirement to omit this functionality is found at only 2% of similar installations worldwide.

62 London Tramlink, who inherited this system, do not know why this functionality was omitted, but this may have been:

a. to comply with HM Railway Inspectorate guidance[7] that 'The throw of the points (unless they lie in a fully segregated place) should only occur when a tram is sufficiently close to them to discourage anyone from being on the moving part, but in enough time for the tram driver to determine the lie of the points before reaching them'; and/or

b. due to a design assumption that trams would be detected by the induction loops in the platforms before a following tram passed the PPI (paragraph 29).

[7] Railway Safety Principles and Guidance, Part 2 Section G Guidance on Tramways, published by HSE Books 1997 (revised and reissued by Office of Rail Regulation November 2006).

Underlying factors[8]

System Integration

63 At East Croydon the track circuit/mass detector provided one barrier to the points moving under or immediately in front of a tram. It is likely that the signalling system was designed on the basis that trams would stop on the loop in the platform and that this, coupled with appropriate operating practices, would act as a second barrier (paragraph 28). TOL were unaware that a tram stopping short of the loop would mean that this second barrier was ineffective. This is consistent with the absence of an absolute requirement for drivers to stop on the loop in platforms at East Croydon (paragraph 30).

64 Although not causal to the accident on 17 February 2012, the requirements needed to integrate track circuits and wheel tyre to wheel tyre resistance were not communicated to the track and vehicle maintainers when Tramlink was commissioned. This is demonstrated by the relatively small difference between maximum permitted wheel tyre to wheel tyre resistance (0.1 ohms, paragraph 57) and the rail to rail resistance of 0.3 ohms given in H&K's operating instructions (paragraph 46).

65 Existing Tramlink standards did not adequately identify how the correct relationship between vehicles and infrastructure should be tested and maintained. The Tramlink system had not been maintained as an integrated system, and the standards to which the point controller and wheel tyre to wheel tyre resistance were being maintained were not sufficient to maintain the correct relationship between the two elements of the system (paragraphs 49 and 57).

Observations[9]

Bombardier's maintenance specification

66 Bombardier's maintenance specification states that wheel shunts (which provide electrical connections between tyres and wheels) should be visually inspected every 20,000 km, and that wheel tyre to wheel tyre resistance for axles on motor (end) bogies should not rise above 0.1 ohms in service. Although this requirement was being met (table 1), Bombardier did not have a testing regime in place to measure these resistances except when bogies were replaced every 600,000 km. At the time of the derailment, a second programme of bogie replacement had commenced as most vehicles in the CR4000 fleet were approaching 1.2 million km. Bombardier considers that visual inspection is sufficient to ensure compliance with a design requirement which it states did not include operating track circuits (paragraph 57).

[8] Any factors associated with the overall management systems, organisational arrangements or the regulatory structure.

[9] An element discovered as part of the investigation that did not have a direct or indirect effect on the outcome of the accident but does deserve scrutiny.

Discounted factors

67 Tramlink's town centre network was closed for engineering work between 12 and 16 February 2012, which prevented some trams returning to their normal depot overnight. During this period, trams continued to access East Croydon tramstop from the east, but tram 2538 was based away from the depot. This had no impact on planned maintenance activity and has been discounted as a factor in this accident.

68 A fault with a hydraulic pump caused points ECR06M to fail on 6 February 2012, and they were out of use until 10 February, when the pump was replaced by H&K, who identified that an electrical isolator switch needed renewing. London Tramlink staff changed the electrical isolator switch on the night of 16/17 February, which allowed points ECR06M to be brought back into full use. Replacement of the pump and switch did not require alteration of any of the settings to the points or the track circuits, and this maintenance work has therefore been discounted as a factor in this accident.

Summary of conclusions

Factors affecting the accident

69 Tram 2538 derailed because points ECR06M moved beneath the vehicle, setting the centre and rear of the vehicle on a diverging route (**paragraph 32**). This occurred because the stopping position of the preceding tram created the circumstances for points ECR06M to be requested to move when tram 2538 was passing over (**paragraph 27, Recommendation 1**).

Causal factors

70 The track circuit which locks points ECR06M did not respond to tram 2538. Consequently the points remained free to move while the tram was passing over them (**paragraph 35**). This was owing to a combination of the following factors:

a. the track circuit voltage was not adjusted in accordance with the manufacturer's operating instructions (**paragraph 44, see paragraph 76**);

b. the likely effect of contamination at the interface between wheels and rails (**paragraph 53, Recommendation 2**); and

c. tram 2538 had a relatively high (but within specified limits) wheel tyre to wheel tyre resistance (**paragraph 56, Recommendation 3**).

71 A non-standard point controller installation meant that protection against points moving under trams relied entirely on correct operation of the track circuit (**paragraph 59, Recommendation 1**).

Underlying cause

72 System integration within Tramlink was inadequate (**paragraph 63, Recommendation 3**).

Observation

73 There were no wheel tyre to wheel tyre resistance checks specified except during bogie overhaul (**paragraph 66**).

Actions already taken or in progress relevant to this report

74 The RAIB issued an Urgent Safety Advice on 01 March 2012 relating to some issues covered in this report, based on emerging evidence. A copy of this advice is included as appendix C.

Actions reported that address factors which otherwise would have resulted in a RAIB recommendation

75 London Tramlink has checked its system for other locations where interaction between tram wheels and the signalling system is critical. East Croydon is the only location on the Tramlink network where release of stored data can create a risk similar to that identified in this report. Other motorised points are located at junctions or on the approach to terminus platforms.

76 Dedicated maintenance equipment has been purchased by London Tramlink to measure the performance of track circuits. The nine track circuits on the Tramlink system which control facing points have been adjusted to respond when a 0.3 ohm test resistance is applied between the rails. This value makes some allowance for rail head contamination. These track circuits are now subject to routine testing although this is not a requirement of H&K's maintenance instructions.

77 London Tramlink has taken direct control of TOL's contract with Bombardier and appointed a Chief Engineer with responsibility for maintenance standards, actions that were in progress prior to the accident. One of the objectives of these actions is for London Tramlink to develop its understanding of how the tramway infrastructure operates and interfaces with trams.

Recommendations

78 The following recommendations are made[10]:

1 *The intention of this recommendation is to promote a review of the signalling and operational arrangements at East Croydon and to take any action needed to make them fit for purpose.*

London Tramlink should review the operational and signalling arrangements at East Croydon to consider whether undue reliance is being placed on the correct operation of track circuits. If found necessary:

- additional measures to alert tram drivers to the stopping position in platforms should be provided (paragraph 69); and/or
- the signalling and/or point control arrangements should be modified (paragraph 71).

2 *The intention of this recommendation is to reduce the risk of rail head contamination affecting the correct operation of track circuits. This should include inspections immediately after events which could lead to accumulation of silt.*

London Tramlink should identify areas of paved track where silt collects and instigate an improved inspection and cleaning regime where such silt may affect the safe operation of the tramway system (paragraph 70b).

3 *The intention of this recommendation is to establish boundary values for tram wheel tyre to wheel tyre resistances and introduce requirements to take appropriate measurements during planned maintenance.*

London Tramlink should conduct a fundamental review of track circuit settings and wheel tyre to wheel tyre resistances and then put in place a system of maintenance that ensures the signalling equipment and trams are maintained to mutually compatible standards, which include due allowance for reasonably foreseeable levels of contamination at the wheel/rail interface (paragraphs 70c and 72).

[10] Those identified in the recommendations, have a general and ongoing obligation to comply with health and safety legislation and need to take these recommendations into account in ensuring the safety of their employees and others.

Additionally, for the purposes of regulation 12(1) of the Railways (Accident Investigation and Reporting) Regulations 2005, these recommendations are addressed to the Office of Rail Regulation to enable it to carry out its duties under regulation 12(2) to:

(a) ensure that recommendations are duly considered and where appropriate acted upon; and

(b) report back to RAIB details of any implementation measures, or the reasons why no implementation measures are being taken.

Copies of both the regulations and the accompanying guidance notes (paragraphs 200 to 203) can be found on RAIB's website www.raib.gov.uk.

Appendices

Appendix A - Glossary of abbreviations and acronyms

H&K	Hanning and Kahl
PLC	Programmable logic controller
PPI	Points position indicator
TOL	Tram Operations Ltd

Appendix B - Glossary of terms

All definitions marked with an asterisk, thus (*), have been taken from Ellis's British Railway Engineering Encyclopaedia © Iain Ellis. www.iainellis.com.

Facing points	A set of points installed so that two or more routes diverge in the direction of travel.*
Induction loop	Insulated wire shaped in a loop, located between the running rails of the tramway, and intended to detect transponders mounted on trams.
Mass detector	An electric oscillating circuit which changes frequency when a metal vehicle passes.
Point controller	Electronic controller responding to inputs from the signalling system, track circuit and mass detector, and outputting to the point motor.
Points position indicator	White position light signals that provide the driver with an indication of how the points are set as the tram approaches.
Programmable logic controller	The Programmable Logic Controller (PLC) is a digital computer used to control electromechanical processes, such as movement of points machinery or route setting visual signals.
Receiver voltage	Voltage measured at the track circuit receiver within the point control cabinet.
Resilient wheels	Wheels assembled with rubber blocks between the steel wheel tyre and wheel hub, designed to reduce noise, vibration and maintenance costs.
Stub axle	A short axle which does not extend for the full width of a vehicle, allowing a low-floor interior for improved access. The CR4000 trams have stub axles on the centre (trailer) bogie.
Switch rail	The thinner movable machined rail section that registers with the stock rail and forms part of a switch assembly.*
Tip	Extreme end of the switch rail.
Track circuit	An electrical or electronic device used to detect the absence of a train/tram on a defined section of track using the running rails in an electric circuit.*
Transmitter voltage	Input voltage to the track circuit. This can be adjusted within the points control cabinet to control the track circuit's sensitivity.
Wheel shunt	An electrical connection between the hub and tyre of a resilient wheel.
Wheel tyre to wheel tyre resistance	Resistance measured between the steel wheel tyres on either end of the same axle.

Appendix C - Urgent Safety Advice issued by the RAIB to all UK tramways 01 March 2012

1. Incident Description			
Incident Report No	**0558**	**Date of Incident**	17 February 2012
Incident Name	East Croydon		
Type of Incident	Derailment of tram at facing points		
Incident Description	At 06:25 on 17 February 2012, tram number 2538 was approaching East Croydon tramstop westbound. The driver observed that a "points set" indication was showing for the left-hand route, towards platform three. As the tram passed over motorised points ECR06M they changed between the first and second bogies, so that the leading bogie took the left-hand route and the centre and trailing bogies took the right-hand route (towards platform two). The centre bogie was dragged into derailment, the pantograph came off the contact wire, and the tram came to a stop. There were about 100 passengers on board the tram, and none of them were hurt. The tram was re-railed by 15:30 hrs the same day, and the route was re-opened by 17:00 hrs. Initial investigations indicate that the tram, 2538, involved in this incident was not detected by the track circuit which locks points ECR06M. The points were commanded to change because platform three was already occupied by a preceding tram, but this command was not executed when tram 2538 initially approached because the preceding tram had not stopped far enough forward to activate the detection loop at the end of the platform three. When it departed, it activated this loop and the points immediately changed, between the bogies of tram 2538.		
Supporting References			

2. Urgent Safety Advice	
USA Date:	01 March 2012
Title:	Wheel tyre to wheel tyre resistance – trams.
System / Equipment:	Trams equipped with resilient wheels, requiring to operate track circuits.
Safety Issue Description:	The tram runs on resilient wheels, with electrical continuity maintained by braided wire bonds bolted between wheel and tyre, four to each wheel. The centre bogies have stub axles, with carbon brushes and cables to maintain electrical continuity between the wheels.
Circumstances:	Factors in the non-detection of tram 2538 by the point locking track circuit were likely to have been the shunt resistance of the tram wheels, and contamination of the rail head (associated with a recent minor flood in a street-running area). The tram involved in the incident was measured, and wheel tyre to wheel tyre shunt resistances were found to be 0.1Ω* (leading bogie, solid axles) and 0.4Ω** to 0.7Ω** (centre bogie, stub axles). Measurement of this parameter had not previously been part of the maintenance process on the Croydon fleet of trams. Wheel to tyre bonds on the tram involved in the incident were observed to be in poor condition. The manufacturers of the track circuits involved (Hanning & Kahl type HFP) state that a tyre to tyre shunt resistance of less than 0.3Ω is required to operate the track circuit satisfactorily. Some UK tram systems specify a maximum wheel to wheel resistance of 0.01Ω.
Consequences	The tram did not operate a track circuit, and consequently points remained free to move while the tram was passing over them.
Safety Advice:	Tram operators should ensure that the vehicles they operate are maintained in a condition that will ensure continued compatibility with the signalling system. In particular, tram operators should check that the wheel tyre to wheel tyre shunt resistance is consistent with reliable operation of track circuits on the tramway. They should also confirm that their inspection and maintenance processes are sufficient to ensure that this resistance does not increase due to the degradation of components such as electrical bonds.

* This value has been superseded by the results given in Table 1 (0.021 ohms and 0.023 ohms), which were obtained after this advice was issued using more accurate testing equipment.

** Resistance values for the centre bogie stub axles were re-tested in May 2012 using more accurate testing equipment. The values at that time were 0.05 ohms and 0.148 ohms.

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