RAIB

Rail Accident Investigation Branch

Rail Accident Report

Train travelling with doors open on the Jubilee line
1 September 2018

Report 06/2019
July 2019

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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This report is published by the Rail Accident Investigation Branch, Department for Transport.

Preface

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. 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.

The RAIB's findings are based on its own evaluation of the evidence that was available at the time of the investigation and are intended to explain what happened, and why, in a fair and unbiased manner.

Where the RAIB has described a factor as being linked to cause and the term is unqualified, this means that the RAIB has satisfied itself that the evidence supports both the presence of the factor and its direct relevance to the causation of the accident. However, where the RAIB is less confident about the existence of a factor, or its role in the causation of the accident, the RAIB will qualify its findings by use of words such as 'probable' or 'possible', as appropriate. Where there is more than one potential explanation the RAIB may describe one factor as being 'more' or 'less' likely than the other.

In some cases factors are described as 'underlying'. Such factors are also relevant to the causation of the accident but are associated with the underlying management arrangements or organisational issues (such as working culture). Where necessary, words such as 'probable' or 'possible' can also be used to qualify 'underlying factor'.

Use of the word 'probable' means that, although it is considered highly likely that the factor applied, some small element of uncertainty remains. Use of the word 'possible' means that, although there is some evidence that supports this factor, there remains a more significant degree of uncertainty.

An 'observation' is a safety issue discovered as part of the investigation that is not considered to be causal or underlying to the event being investigated, but does deserve scrutiny because of a perceived potential for safety learning.

The above terms are intended to assist readers' interpretation of the report, and to provide suitable explanations where uncertainty remains. The report should therefore be interpreted as the view of the RAIB, expressed with the sole purpose of improving railway safety.

Information about casualties is based on figures provided to the RAIB from various sources. Considerations of personal privacy may mean that not all of the actual effects of the event are recorded in the report. The RAIB recognises that sudden unexpected events can have both short and long term consequences for the physical and/or mental health of people who were involved, both directly and indirectly, in what happened.

The RAIB's investigation (including its scope, methods, conclusions and recommendations) is independent of any inquest or fatal accident inquiry, and all other investigations, including those carried out by the safety authority, police or railway industry.

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Train travelling with doors open on the Jubilee line, 1 September 2018

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Summary

Shortly after 09:00 hrs on Saturday 1 September 2018, a London Underground Jubilee line train travelled between Finchley Road and West Hampstead stations with doors open at ten passenger doorways. The train, with approximately 30 passengers on board, reached a maximum speed of 62 km/h during the 56 second journey between the two stations. No-one fell out of the train and nobody was injured.

When the train stopped at Finchley Road station, some of the doors on the train, which was operating in automatic train operation mode (ATO), opened without being commanded to do so by the train operator. The operator's controls did not allow him to open any doors, nor close any doors. It is likely that the door behaviour was due to control system overload caused by faults elsewhere on the train. While dealing with the door issue, the train operator operated a switch, bypassing the door interlock circuit that was intended to prevent the train departing with doors open. He then did not notice that some doors remained open when departing from Finchley Road station and travelling to West Hampstead. The train operator's actions were probably influenced by:

- a sudden increase in his workload from the low level associated with automatic train operation;
- fatigue from his sleeping pattern; and/or
- low blood-sugar levels from a prolonged period without food.

An underlying factor was that, unlike some other London Underground trains and contrary to London Underground standards, the type of train involved in the incident could be driven with the door interlock circuit bypassed without an audible warning being provided to the train operator. A possible underlying factor was that the training of train operators did not adequately prepare them to manage the sudden increase in workload caused by the need to deal with faults, under time pressure, on trains operating in automatic mode.

The RAIB has made four recommendations addressed to London Underground. These include improvements to door control systems on Jubilee line trains; better training to help train operators respond correctly when sudden increases in workload occur while operating trains in automatic mode; raising train operator awareness of the adverse effects on safety from insufficient sleep and inappropriate eating patterns; and improved management of train faults.

The investigation also identified three learning points relating to the incident. These concern making sure that training, rules and procedures highlight the safety implications of operating sealed switches; understanding that careful checking that the correct switch has been operated when attempting to rectify technical faults is more important than timekeeping; and the importance of staff managing their work/life balance so that safety performance is not adversely affected.

Introduction

Key definitions

1 Metric units are used in this report, in accordance with normal practice on London Underground.

2 The terms left-hand and right-hand are in the context of the train's direction of travel and references to 'control' in this report mean Jubilee line control.

3 The report contains abbreviations and acronyms. These are explained in Appendix A. Sources of evidence used in the investigation are listed in Appendix B.

The incident

Summary of the incident

4 Shortly after 09:00 hrs on Saturday 1 September 2018, a London Underground train travelled on the Jubilee line between Finchley Road and West Hampstead stations in north-west London (figure 1) with doors open at ten passenger doorways.

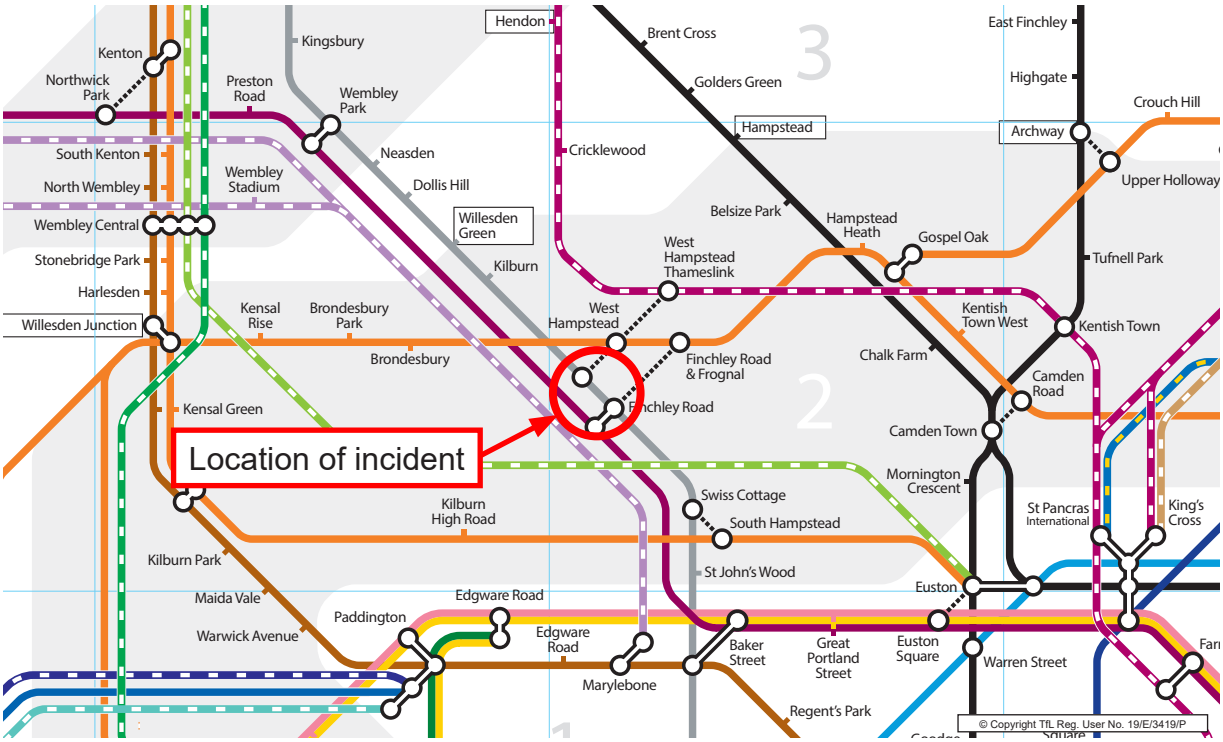

Figure 1: Extract from London Underground map showing location of accident (courtesy of Transport for London)

5 The train travelled for 56 seconds and reached a maximum speed of 62 km/h between the two stations. There were approximately 30 passengers on the train but no-one fell out of it during the journey to West Hampstead, and there were no reported injuries or damage.

Context

Location

6 The incident happened on London Underground's Jubilee line which runs from Stratford in east London to Stanmore in north-west London (figure 2). Finchley Road station, West Hampstead station and the 600 metres of track between them are all on a surface section of the Jubilee line. London Underground's Metropolitan line runs adjacent to the Jubilee line between Finchley Road and West Hampstead stations (figure 2 inset). At Finchley Road station, northbound Jubilee line trains such as the train involved in the incident use platform 2, which was on the left-hand side of the train (figure 3). When stopping at West Hampstead station, the platform was on the right-hand side of the train.

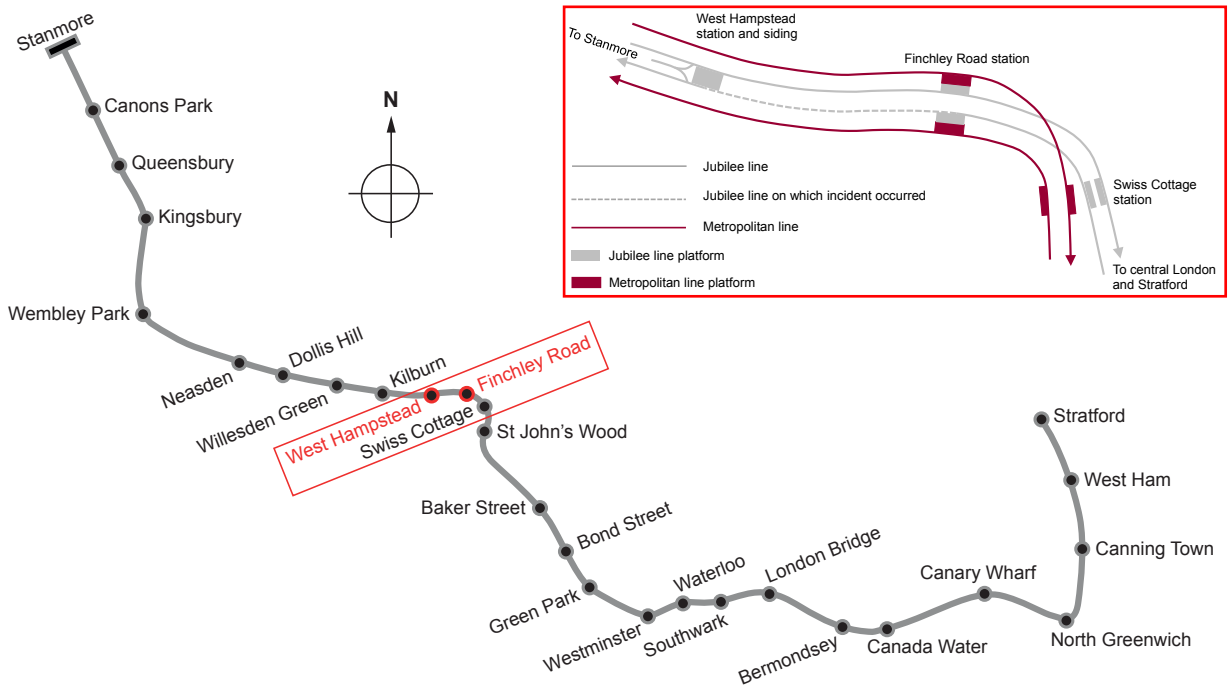

Figure 2: The Jubilee Line

Figure 3: Platform 2 at Finchley Road

Organisation involved

7 London Underground Limited (LUL) owned, operated and maintained the infrastructure and the train involved in the incident. It also employed the train operator.

8 LUL freely co-operated with the investigation.

Train involved

9 The train involved was formed of 1996 tube stock and comprised seven cars. When introduced on the Jubilee line, these trains were configured for manual operation in which the train operator controls the speed of the train between stations using a controller to apply power or brakes as appropriate. The trains were converted to allow automatic train operation (ATO) between 2006 and 2008. In accordance with current normal practice on the Jubilee line, the train was running in ATO at the time of the incident.

10 When running in ATO, movement of the train is controlled automatically. At stations, the train operator is responsible for opening and closing the passenger doors, checking in-cab CCTV monitors for potential issues at the platform-train interface (eg passengers or objects trapped in closed train doors) and initiating the start of the train. Between stations, the train operator is expected to monitor the ATO system, remain vigilant and look out for any obstruction on the track ahead of the train.

11 The train operator sits in the driving cab at the front of the train with a control console in front of them. This console includes the buttons normally used to operate the passenger doors, CCTV monitors and other train controls. A cab door is provided on both sides of the driving cab behind the driver. On the back wall of the driving cab, beside each cab door, are buttons for opening and closing the cab door and buttons sometimes used to operate the passenger doors. Adjacent to these buttons is a bank of bypass switches only used when responding to train faults (figures 4 and 5).

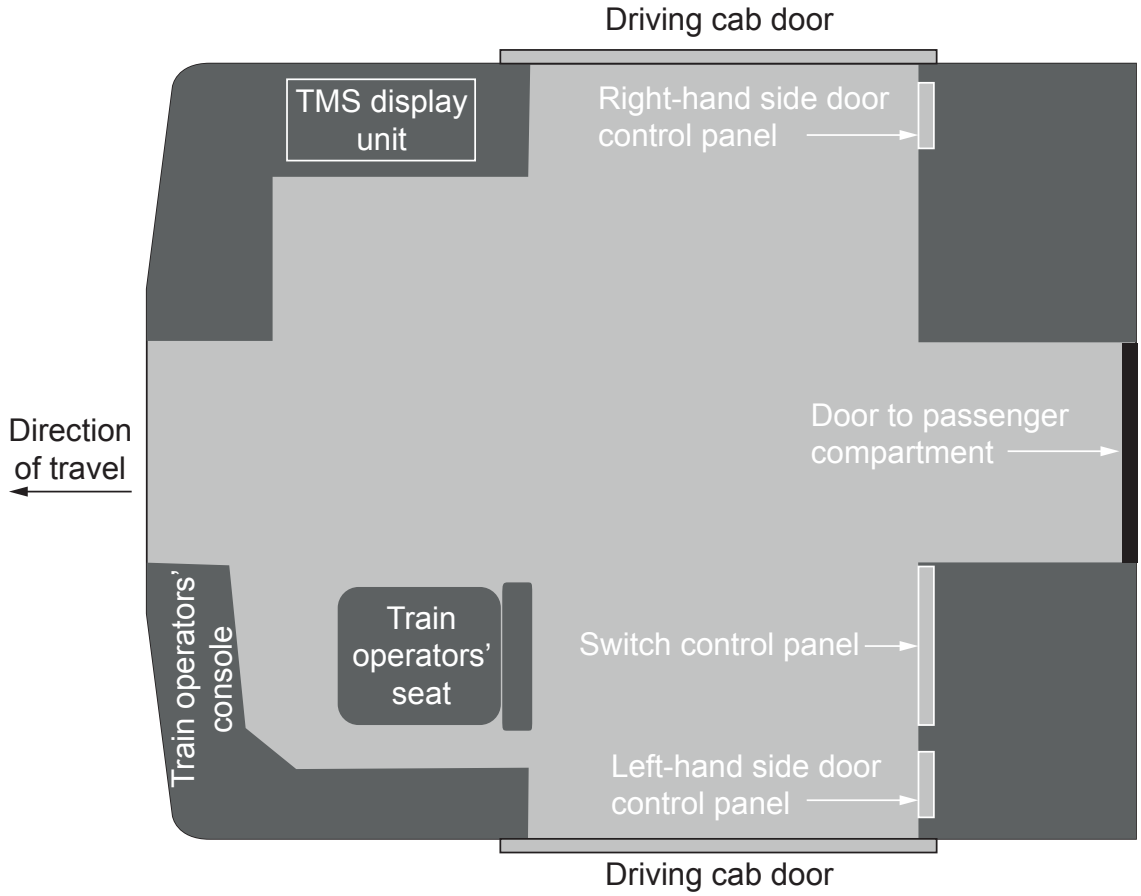

Figure 4: Simplified plan of driving cab

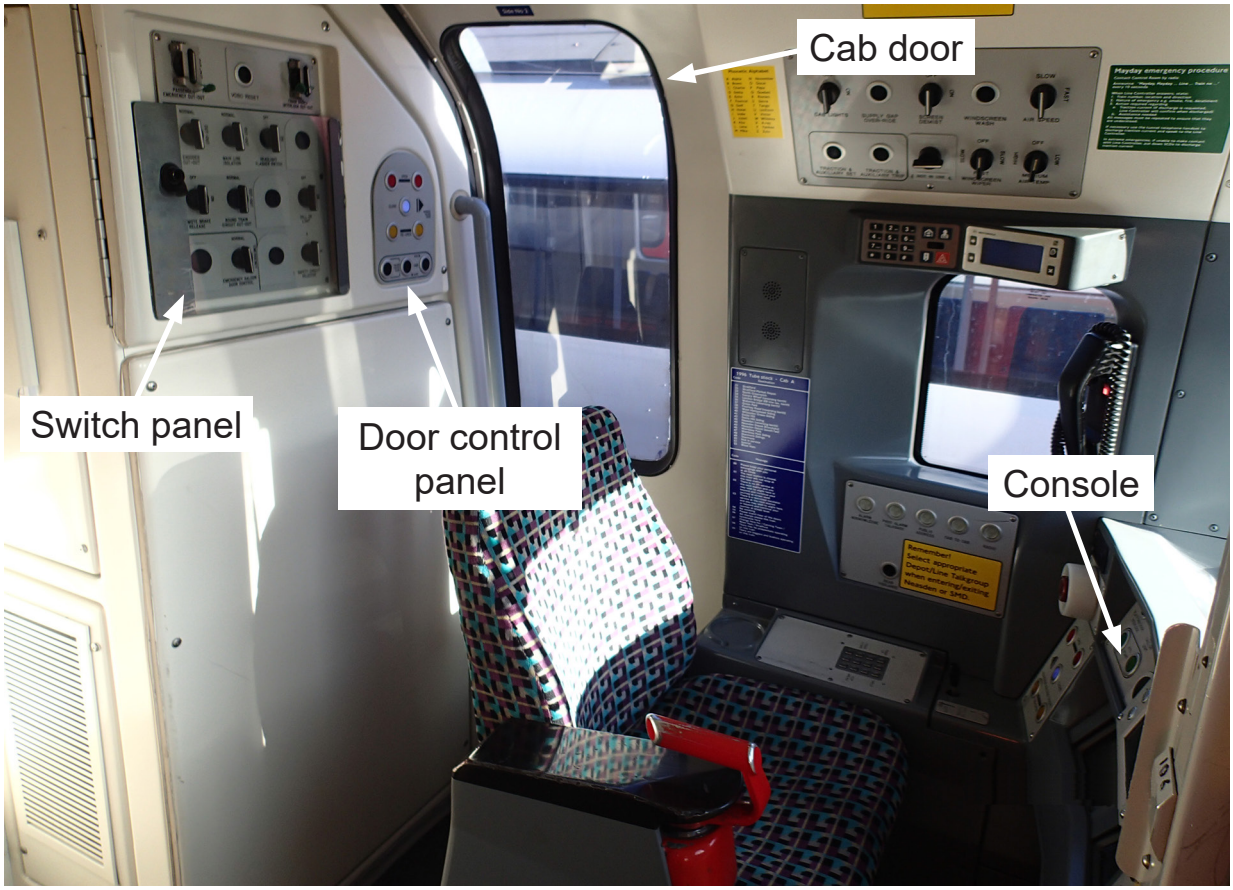

Figure 5: Driving cab

12 The passenger doors are normally controlled by the train operator using two sets of buttons on the driving cab console (figure 6). The set on the left-hand side of the console operates doors on the left-hand side of the train, and the set on the right-hand side of the console operates the right-hand side doors. Each set includes two door-open buttons which must be pressed simultaneously before the doors open on the appropriate side of the train (this normally opens all doors immediately, but did not do so during the incident). The push buttons illuminate red as soon as they are pressed and remain illuminated until the door-close button is pressed.

13 Passenger doors are normally closed by the train operator pressing the door-close button on the console on the side for which door closure is required (figure 6). This normally closes all doors on that side of the train. Full closure of all doors completes the door interlock circuit, which causes the door-close buttons to illuminate blue; this indication is known as the doors closed visual (DCV). If any of the doors are not detected as fully closed, the DCV lights stay unlit. When the door-open buttons are pressed at a station the DCV blue lights go out.

14 To assist train operators when deciding if it is safe to close the doors and when monitoring the platform edge as the train departs from a station, the console includes two CCTV monitors (figure 7). These monitors receive live images from CCTV cameras positioned along the platform. Each monitor shows two images such that the whole length of the side of the train alongside the platform is displayed over four images across the two monitors (figure 8).

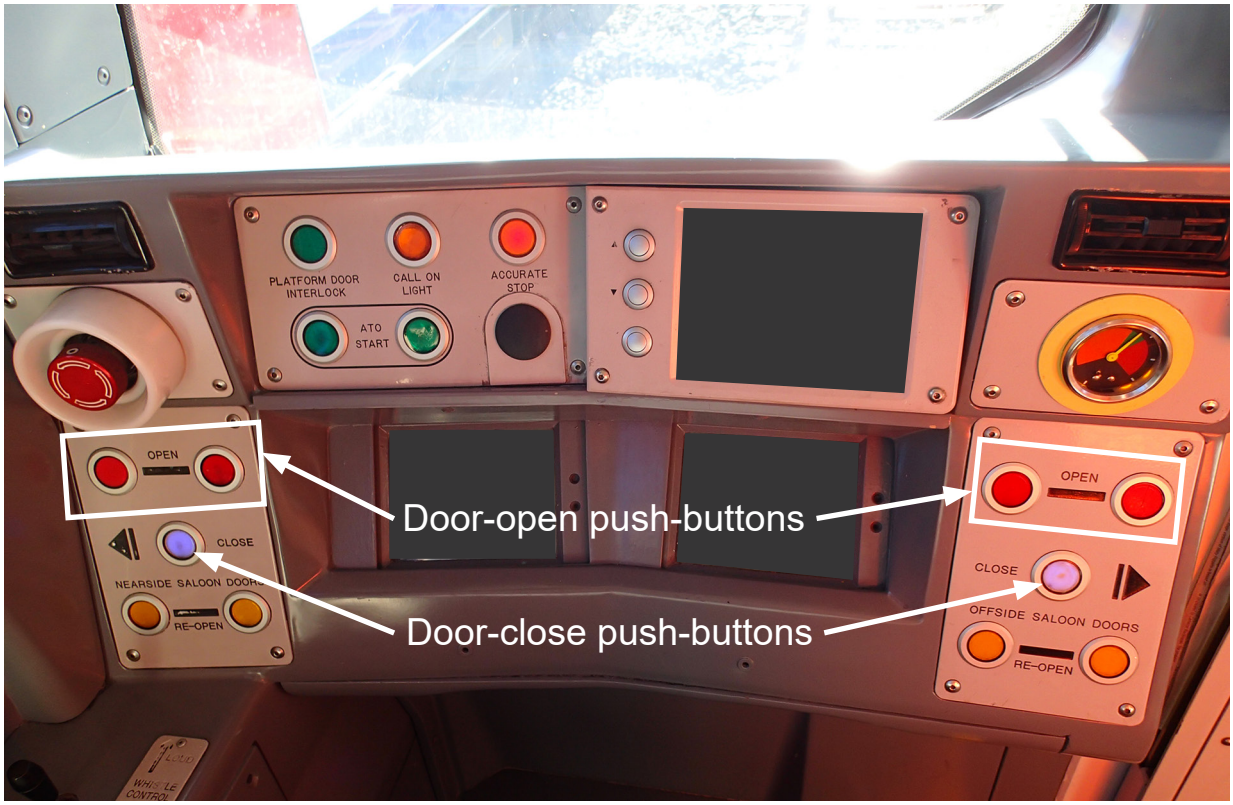

Figure 6: Train operator's passenger door-open and close buttons

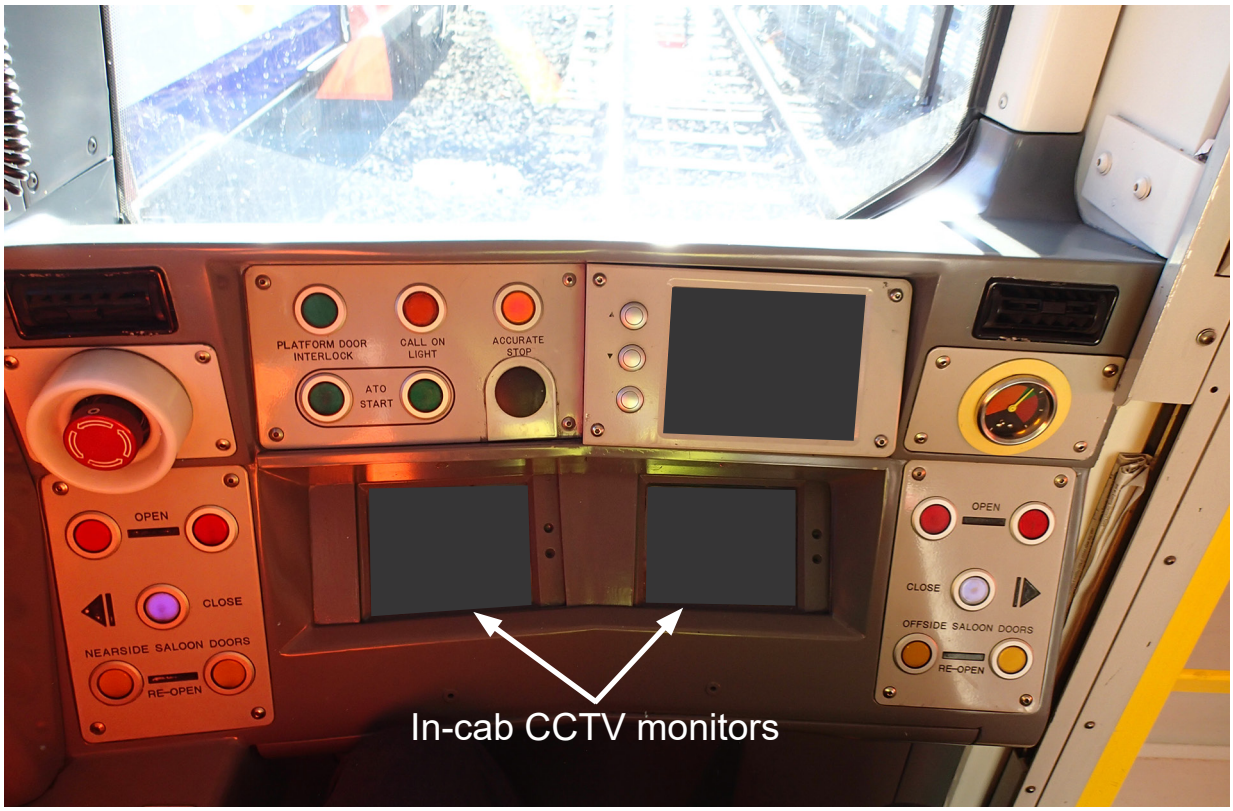

Figure 7: CCTV monitors on console

Figure 8: Images shown on CCTV monitors

15 The ATO system is intended to optimise the interval between successive trains based on real-time train running information. The system calculates the optimum dwell time (the length of time a train is stationary at a platform) for each station stop and presents this to the train operator on an in-cab countdown display showing the number of seconds before the desired departure time. When there are approximately 10 seconds of calculated dwell time remaining a warning tone sounds in the driving cab. The display then shows 'ATO Start Required' after the calculated optimum departure time has passed (figure 9).

16 When the train is ready to depart from a station, the train operator presses two ATO start buttons simultaneously on the console (figure 9). This action removes the 'ATO Start Required' display and, around 4 seconds later, the train will start to move.

17 The banks of cut-out switches on the cab back wall include the 'train door interlock cut-out' (TDIC) switch (figure 10) which bypasses the safety system intended to prevent the train moving with doors open. The switch bank also includes the emergency saloon door control switch (ESDC, figure 10) which enables the train operator to open passenger doors using the door-open buttons on the driving cab back wall when normal door operation is disabled, for example if the train has not stopped close to the normal stopping point at a station (ie when the train has not achieved an accurate stop).

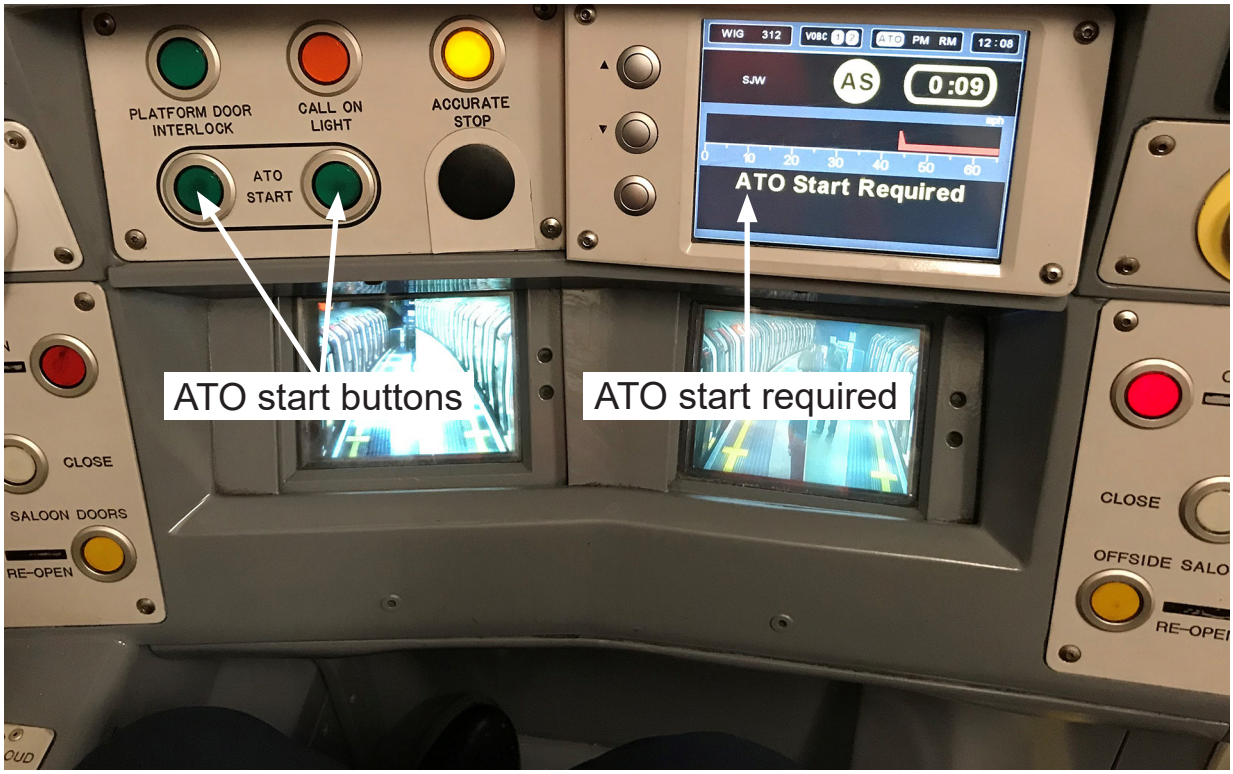

Figure 9: ATO display showing ATO start required and ATO start buttons

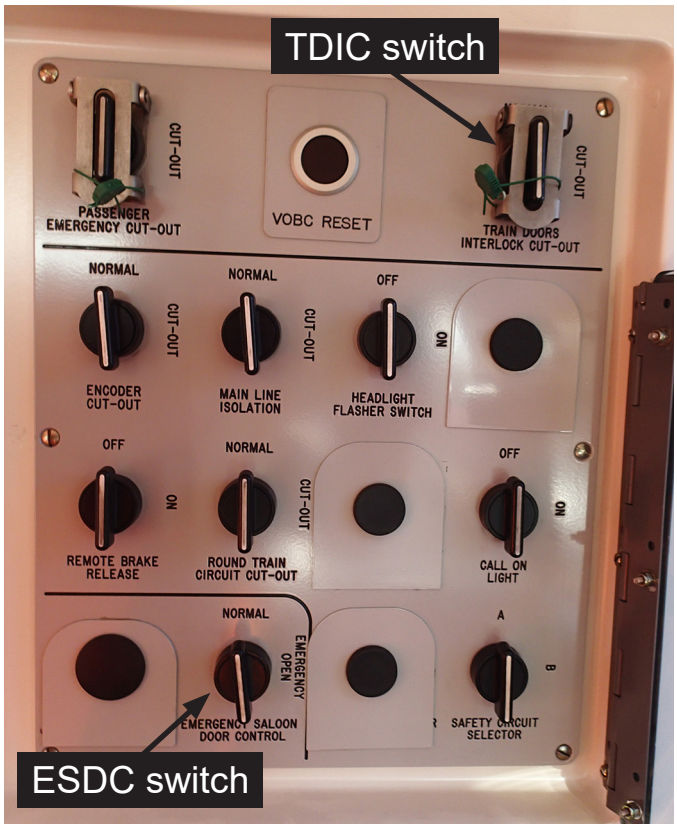

Figure 10: TDIC and ESDC switches on driving cab panel (location of panel shown on figure 5)

18 In addition to passenger doors being opened by the train operator (paragraph 12), the trains were originally fitted with equipment allowing opening of individual doors by passengers. This function was enabled by a selector switch on the cab back wall, which allowed passengers to open doors using buttons on the inside and outside of the train at each doorway. This mode of operation was not normally used and, in June 2018, LUL began to disable the internal door-open buttons and to remove both the external door-open buttons and the driving cab selector switches. At the time of the incident, the driving cab selector switch had been removed from the incident train but the doorway buttons had not yet been modified.

Staff involved

19 The train operator involved in the incident joined LUL in January 1999, originally working as a station assistant, before becoming a train operator on the Jubilee line in December 2007.

20 His most recent driving assessments before the incident were on 31 January 2018 and 5 July 2018 as part of his regular competence management cycle. On both occasions the assessor noted that the train operator met the necessary competence requirements, including those relating to station stops and operating the doors, with no issues identified. On 9 February 2018 the train operator had a routine performance and development review with an LUL manager; again no issues were identified. He last received training in dealing with faults and failures in January 2018 and this included faults associated with doors failing to open or close.

21 The train operator was medically examined after the incident and found to be fit for train driving duties without needing corrective glasses.

22 At the time of the incident, LUL had no safety concerns about the train operator and there were no disciplinary actions on his records. In November 2017 and April 2018 he received commendations for dealing with an injured passenger and for identifying when a passenger's clothing became trapped in closed train doors.

External circumstances

23 The incident occurred on a bright sunny morning. The bright sunlight is apparent on images recorded by the station CCTV and may have affected the in-cab CCTV images that the train operator was presented with (paragraph 72).

The sequence of events

Events preceding the incident

24 The train operator began his shift at Wembley Park depot at 06:59 hrs. His first duty was to take train 335 southbound from Neasden to Stratford, departing from Neasden at 07:24 hrs.

25 The train operator next drove train 305 which departed on time from Stratford at 08:23 hrs with an intended destination of Wembley Park. The train operator reported that the journey was normal until the train arrived at Finchley Road station, approximately on time, at 08:55 hrs.

26 When train 305 came to a stop in the platform the train operator pressed both door-open buttons on the platform (left-hand) side of his console, expecting that this would open all passenger doors on that side of the train.

Events during the incident (table 1)

27 A few seconds after the train operator had pressed the door-open buttons, he noticed on the in-cab CCTV monitors that a passenger was standing at a closed door. The train operator then repeatedly pressed the door-open and door-close buttons in an attempt to get all the passenger doors to open. The ATO dwell timer sounded during this time to inform the train operator that the train's departure was due in 10 seconds time.

28 The train operator stated that he then stood up, opened the driving cab door adjacent to the platform, put one leg out onto the platform, looked along the side of the train and saw that some other passenger doors had not opened. The on-train data recorder (OTDR) fitted to the train shows the cab door started to open 1 minute and 21 seconds after the train stopped at Finchley Road and that, about 2 seconds later, the train operator bypassed the door interlock circuit by operating the TDIC switch.

29 The OTDR then recorded several operations of the passenger door-open and close buttons by the train operator while the cab door was open (figure 11). The OTDR does not indicate which buttons were used (console or back wall) but it is likely that the train operator remained at the cab door and so used the back wall buttons. The train operator stated that, between opening and closing the cab door, he looked through the peephole in the door leading from the driving cab into the saloon of the first car and saw that no passengers were standing at closed doors waiting to get off the train in the leading car (when looking through the peephole, only the interior of the leading car can be seen).

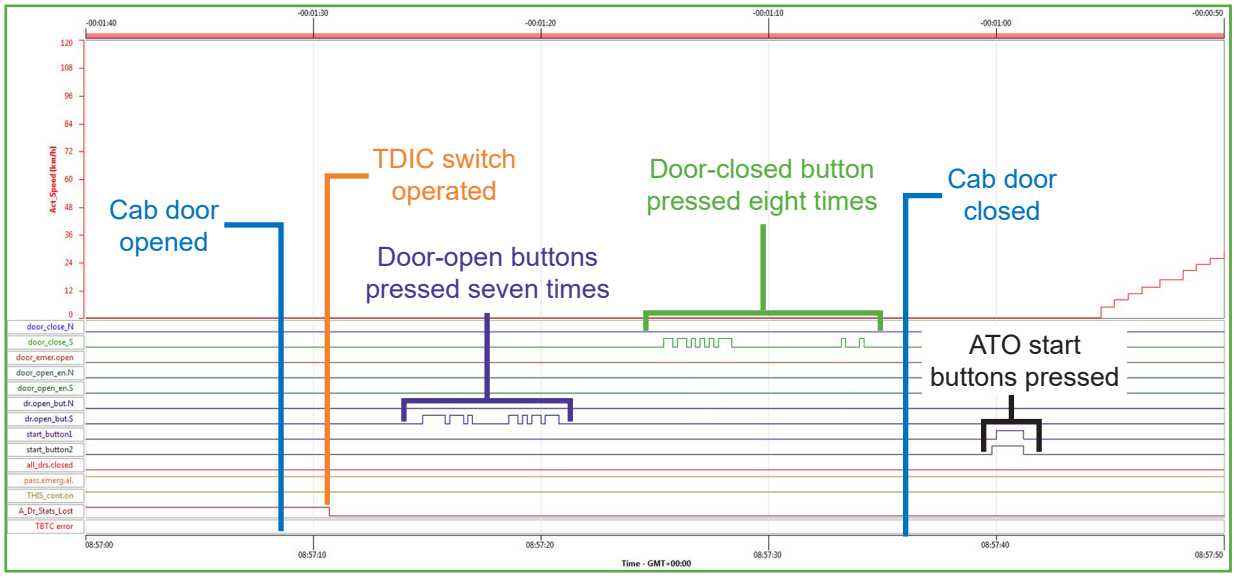

Figure 11: Annotated OTDR graphic showing TDIC switch operated, cab door operation, and operation of door-open and close buttons

Time (hh:mm:ss)	Time from stopping (mm:ss)	Door-open buttons pressed	Door-closed buttons pressed	Other events
08:55:48	00:00			
08:55:50 to 08:56:12	00:02 to 00:24	15 times		ATO dwell timer sounds in driving cab at 08:56:12 (24 seconds after stopping)
08:56:13 to 08:56:24	00:25 to 00:36		9 times	ATO dwell timer reaches zero at 08:56:22 (34 seconds after stopping)
08:56:28	00:40	Once		
08:56:30 to 08:56:36	00:42 to 00:48		8 times	
08:56:50	01:02	Once		
08:56:54 to 08:56:56	01:06 to 01:08		3 times	
08:57:09	01:21			Cab door opened
08:57:11	01:23			TDIC switch operated
08:57:13 to 08:57:19	01:25 to 01:31	7 times		
08:57:24 to 08:57:32	01:36 to 01:44		8 times	
08:57:36	01:48			Cab door closed
08:57:40	01:52			ATO start buttons pressed
08:57:45	01:57			Train begins to move

Table 1: Sequence of events recorded by the train's OTDR

30 The train operator then returned to his driving seat and made an announcement to the passengers apologising for the door problem and saying he would deal with it at the next station. After making the passenger announcement, the train operator pressed the ATO start buttons about 1 minute 52 seconds after arriving at Finchley Road station, but he did not notice that the DCV lights had not illuminated. He used his hands to shield the in-cab monitors from sun glare as he watched the train's departure from the platform. He did not notice that some train doors were open as the train was departing.

31 Images from CCTV cameras on the station and in the train show that, while at Finchley Road station, some of the train's doors opened after passengers pushed the associated internal or external doorway buttons, and that some doors opened with no passenger action. The images also show that some doors did not open, but it is not certain from the CCTV images whether passengers had pushed the associated doorway open button at any of these doors.

32 During the 56 second journey to West Hampstead, internal train CCTV shows doors were open at 10 of the 28 passenger doorways (figure 12).

33 The train operator did not call control (ie the Jubilee line control room) while he was at Finchley Road station to tell them there was a problem with the train, and control did not call him. Control would not normally call a train operator unless a delay exceeded two minutes. The train was at Finchley Road station for less than two minutes and LUL train performance records show that it departed 1 minute 19 seconds later than timetabled.

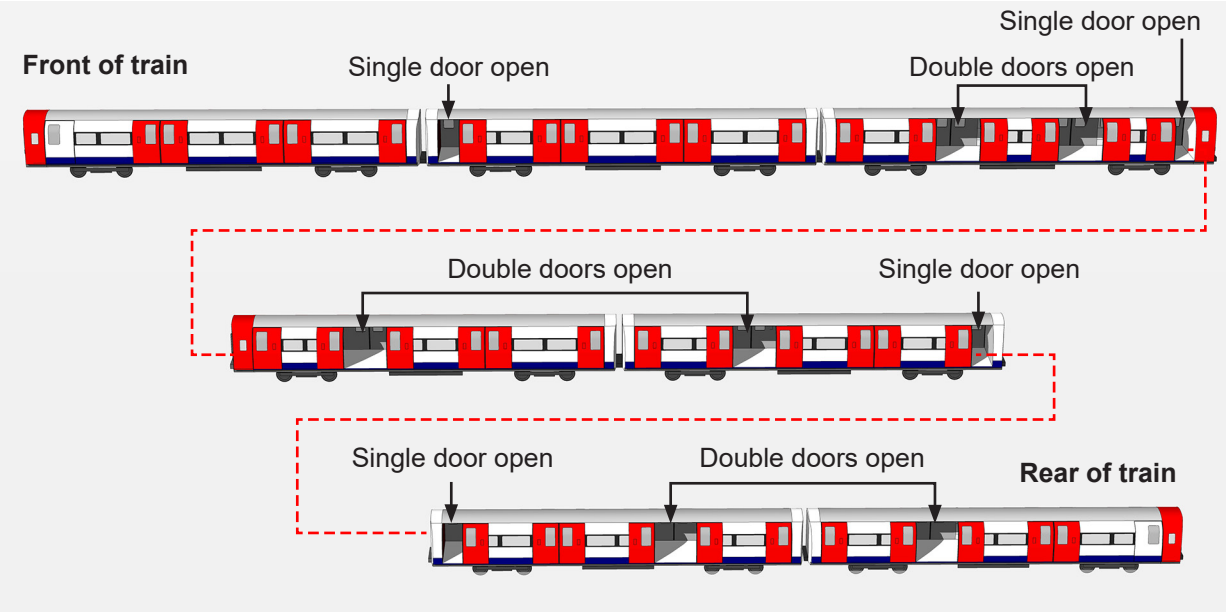

Figure 12: Location of open doors on the train (note some doorways have single doors and some have double doors)

Events following the incident

34 When the train arrived at West Hampstead station, the platform was on the right-hand side of the train and all passenger doors on this side of the train opened normally when the train operator pressed the console door-open buttons. The train operator stated that after opening the doors he turned around and noticed that he had operated the TDIC switch, and so he turned the switch back to its normal position. Around this time a passenger operated a passenger alarm inside the train and told the train operator that some doors had been open on the journey from Finchley Road station. The train operator reported this to control and then went back to examine the train, where he found doors open at 10 of the 28 doorways on the left-hand side of the train (the side of the train not alongside the platform at West Hampstead).

35 Trains in both directions on the Jubilee line were then told by control to proceed cautiously between Finchley Road and West Hampstead stations until it was determined that no passengers had fallen out of the train. There were no trains running on the Metropolitan line between these locations due to engineering work.

36 The train involved in the incident was taken out of service at West Hampstead and taken to Stratford depot for post-incident testing.

Key facts and analysis

Background information

Door opening procedure

37 In normal ATO operation, the train stops automatically at the correct location, and this is confirmed by an accurate stop detection system, consisting of equipment fitted to the train and on the track, which causes a yellow 'accurate stop' light to illuminate on the train operator's console (figure 13). The train operator then opens the passenger doors on the appropriate side of the train.

38 If the doors do not open when the train has accurately stopped at the correct location, the train operator is expected to follow the procedures given in LUL's 1996 stock 'defect guide' version 1, dated June 2012 (table 2) and LUL's 'defective in service' instructions, issue 3, dated December 2015 (table 3). For the scenarios covered by these documents, they require passengers to be detrained and the train withdrawn from service if more than one door fails to open after applying the procedures given in the documents.

39 In some instances trains do not stop accurately and the yellow light will not illuminate. LUL stated that this happens at about 0.017% of station stops. In these circumstances train operators are trained to open the cab door to check whether the train has stopped with all passenger doors alongside a part of the platform where they can be used safely by passengers.

40 If the train has stopped in a position where passengers can leave the train safely from all doors, train operators are required to open the doors using the ESDC switch, following the procedure given in the 1996 stock defect guide (table 2). If the doors still fail to open, they are then required to follow the instructions in the defective in service instructions (table 3). If, after attempting to open doors using the ESDC switch more than one door still fails to open on the platform side of a train, the 'defective in service' instructions require that the train is withdrawn from service, a process which includes detraining passengers.

Figure 13: ATO accurate stop indicator

Problem	Procedure
All doors failing to open on one car	▪ Try door control buttons again. ▪ Inform the controller. ▪ Check TMS1 miniature circuit breaker in affected car.
All doors failing to open on the whole train	▪ Inform customers of delay for doors to be opened. ▪ Operate ESDC switch. ▪ Operate back wall door-open buttons. ▪ Return ESDC switch to normal position. ▪ If doors still do not open then use outside door valves to detrain passengers.

Table 2: Summary of 1996 stock defect guide instructions if doors fail to open

Problem	Procedure
One doorway failing to open on one car	▪ Train can remain in service to a depot.
More than one doorway failing to open on platform side	▪ Withdraw train from service.

Table 3: Summary of defective in service instructions if doors fail to open with train at accurate stop

Despatch procedure

41 LUL rules for train despatch, shown in London Underground Operational Standards Rule Book 8: 'Managing the platform train interface' (issue 5, June 2017), state that the train operator must:

- *check the station starting signal is clear*
  [although not stated in the rule, the movement authority displayed on the ATO screen provides the equivalent information in Jubilee line ATO mode]
- *check the entire platform train interface*
- *close the doors and check the doors closed visual [DCV]*
- *check the entire platform train interface again*
- *check that the station starting signal is still clear*
- *make a final check of the platform train interface*
- *start your train*
- *check the in-cab monitors (if fitted) as your train leaves the platform.*

42 In normal ATO operation, door closure is achieved using the appropriate door-close button on the console and the visual platform-train interface checks are made using the in-cab CCTV monitors (paragraph 14). Full closure of all doors is proved by illumination of the DCV lights (paragraph 13).

43 If the DCV lights do not illuminate, LUL's rules for train despatch require train operators to:

- Re-open and close the doors, several times if necessary, and if the DCV lights still do not illuminate, train operators must tell control, arrange for the passengers to be detrained, and withdraw the train from service.
- Not operate the TDIC switch until they have confirmed that all doors are closed.

44 The 1996 stock defect guide also contains information relating to doors failing to close (table 4). If the doors do not close after applying procedures given in this document, and depending on the exact situation, it instructs train operators to inform control. Although not always stated in the defect guide, informing control should be followed by acting on control's instructions. The 'defective in service' instructions (table 5) do not deal specifically with a door not closing but do contain instructions about whether a train can remain in service after a door problem has been encountered.

Problem	Procedure
A single door failing to close	▪ Check for any obstructions. ▪ Attempt to close the door again. ▪ If door cannot be closed, inform control.
All doors on one car failing to close	▪ Use the porter's button to close doors (a porter's button is located on the outside of each car). ▪ If doors still do not close then check and reset relevant door miniature circuit breakers. ▪ If doors still do not close then inform control and: ▪ operate the door isolating cock in affected car and manually close the doors; and ▪ operate the TDIC switch.
All doors on the train failing to close	▪ Shut down the driving cab; and trip and reset TMS2 miniature circuit breaker. ▪ If the fault persists then try to close the doors using close buttons in another driving cab. If doors still do not close then: ▪ Inform control and act on instructions given.

Table 4: Summary of 1996 stock defect guide instructions if doors fail to close

Problem	Procedure
One door close button fails to operate	▪ Train can remain in service to a depot.
All door close buttons fail to operate	▪ Withdraw train from service.

Table 5: Summary of 'defective in service' instructions if door close buttons are defective

45 If a defective door cannot be closed at a station, LUL's Operational Standards Rule Book 7: 'Train incidents and safety equipment' (issue 6, June 2017) requires train operators to not move the train and to:

- *tell the controller;*
- *detrain customers; and*
- *wait for assistance.*

46 Some control switches used by train operators dealing with unusual events, including the TDIC switch used when dealing with door faults, are fitted with seals (plastic ties) which must be broken before the switch can be operated. Although there is no LUL requirement for train operators to inform control before breaking seals, there are LUL procedures relating to moving trains with these switches operated. These procedures include contacting control before departing from a station with the TDIC switch operated.

Identification of the immediate cause

47 **The train departed and then subsequently travelled between two stations with passenger doors open at 10 of the 28 doorways.**

Identification of causal factors

48 The incident occurred due to a combination of the following causal factors:

- Some doors opened at Finchley Road station without being commanded by the train operator and none subsequently responded to him using the door-open and close controls in the driving cab (paragraph 49);
- the train operator did not follow LUL procedures and bypassed the door interlock circuit, which is intended to prevent trains departing with some doors open and passengers on board (paragraph 53);
- the train operator was unaware that some doors remained open when he started the train and as it travelled to West Hampstead (paragraph 65); and
- it is probable that the train operator's actions were influenced by a sudden increase in his workload, fatigue and/or low blood-sugar levels (paragraph 78).

Each of these factors is now considered in turn.

49 Some doors opened at Finchley Road station without being commanded by the train operator and none subsequently responded to him using the door-open and close controls in the driving cab.

50 On the morning of the incident the train's doors had operated as expected at the 16 station stops from Stratford to Swiss Cottage, the station before Finchley Road, but did not do so at Finchley Road station (this and subsequent references to train doors refer only to passenger doors unless described otherwise). It is likely that the unusual behaviour of the doors at Finchley Road station resulted from a loss of communication between items of train control equipment, coupled with defects in some of the door-open buttons provided at passenger doorways. It is probable that communication was lost when part, or parts, of the train management system rebooted (restarted) after being overloaded by multiple fault messages generated by defective ventilation fan equipment and defective passenger information systems.

51 The control system status causing the doors to behave unusually at Finchley Road station developed during the 59 seconds after the train started from the preceding station where the doors had behaved normally. It is possible that this control system status had existed on previous occasions but was not noticed because there was little or no overlap with the times when doors were commanded to open or close.

52 LUL and RAIB have identified the likely technical explanation for the train door behaviour at Finchley Road station. A summary of this work, and the reasons for uncertainty about some details, is presented in Appendix C. The following points are of particular relevance:

- The train control equipment included train management car controllers (TMCCs) which were designed to reboot during some fault conditions. It is likely that this happened as the train was arriving at Finchley Road station, due to the large number of fault messages associated with defective ventilation fans and passenger information systems.
- TMCCs were duplicated on the train with the intention that a hot standby unit (ie primed and ready to operate) would take over when a 'live' TMCC rebooted, but it is likely that this feature did not function as intended at Finchley Road.
- Train management remote terminals formed part of the door control system and were connected to the TMCCs. These remote terminals were designed to permit passengers to open doors using buttons at doorways if they lost communication with associated TMCCs (for example because the master and hot standby units were rebooting or not functioning).
- LUL was aware of the reboot features but was unaware of the duration or frequency of rebooting as there was no means of recording this, and the hot standby arrangement would normally prevent TMCC reboots affecting train operation.
- The large number of fault messages relating to defective ventilation fans and passenger information systems had been recorded by on-board equipment for two days before the incident, but LUL was unaware of this as there was no process for routinely downloading and reviewing fault records.
- Although the door-open buttons at doorways were no longer intended for use (paragraph 18), they had not been disconnected, and some were defective.

Train operator's actions

53 The train operator did not follow LUL procedures and bypassed the door interlock circuit, which is intended to prevent trains departing with some doors open and passengers on board.

54 The door behaviour at Finchley Road was unusual and not directly covered by the train operator's training, by the 1996 stock defect guide or by the defective in service instructions (tables 1 to 5). However, following the instructions for any of the door fault scenarios given in these documents and/or contacting control would almost certainly have led either to corrective action resulting in all doors being correctly opened and then closed, or to the train being taken out of service at Finchley Road.

55 LUL documentation cannot cover every fault scenario. The train operator could have concluded that the situation was outside his training and the scenarios covered by LUL documentation. However, in these circumstances, LUL rules require train operators to contact control, an action which would have almost certainly meant that the incident would not have occurred at Finchley Road.

56 When the doors failed to respond to the normal door-open buttons, the train operator stated that his intention was to open the doors using the ESDC switch, which would have been consistent with the defect guide instructions for all train doors failing to open. It is uncertain, for reasons explained in Appendix C, whether correct application of this procedure would have resulted in all doors opening, and then all doors closing. The LUL procedures for using the ESDC switch do not require the train operator to contact control if doors then open and close as expected.

57 Although the train operator stated that he intended to operate the ESDC switch, he actually operated the TDIC switch and did not follow the appropriate procedures. He stated that he:

- wanted to see if the fault repeated itself at the next station, and if it did so, he would call control and take the train out of service there;
- was relying on his memory of what he should do and so did not refer to the 1996 tube stock defect guide or LUL's 'defective in service' instructions;
- believed LUL expected train operators to fix problems where they could; and
- felt under time pressure to depart having heard the ATO dwell timer sounding and not wanting to delay train services.

Operating the TDIC switch

58 The train operator bypassed the door interlock circuit by operating the TDIC switch while attempting to open doors alongside the platform at Finchley Road station.

59 The train operator stated that he had opened the cab door, put one foot on the platform to look along the train, and then reached back into the cab and operated the switch without first checking that he was operating the intended switch (the ESDC switch). The OTDR shows that the cab door started to open 1 minute and 21 seconds after the train stopped at Finchley Road, and that about 2 seconds later, the train operator bypassed the door interlock circuit by operating the TDIC switch.

60 The RAIB simulated the train operator's actions and observed that, from pressing the cab door-open button, it takes around 1.8 seconds for the cab door to open. This suggests that the train operator was putting his hand onto the TDIC switch before or while leaving the cab, as the time taken to open the door, step out onto the platform and reach back in to operate the TDIC switch would exceed the two seconds between the cab door starting to open and operation of the TDIC switch.

61 Both the ESDC and TDIC switches are part of the cut-out switch bank on the back wall of the driving cab, near the cab door which was adjacent to the platform (figures 5 and 10). However, there are significant differences between these switches; the TDIC switch is at a higher level and nearer the cab door than the ESDC switch. The TDIC switch is fitted with a flap and a seal in the form of a plastic tag which must be broken before the switch can be operated. The flap covers only the TDIC switch and must be lifted before the switch can be turned. The ESDC has no seal or individual flap. However, it can only be operated after opening a plastic door which covers most of the switch bank, but not the TDIC switch. This plastic door opens towards the driving cab door, which makes operating the ESDC switch from the doorway difficult.

62 The TDIC switch is fitted with a protective flap and plastic seal because it bypasses the door interlock circuitry which prevents a train operating with passenger doors open. LUL's rules do not allow trains with the door interlock circuit bypassed to carry passengers except in exceptional circumstances: for example, if a train must be moved into a platform to allow passengers to be detrained and the train then withdrawn from service. LUL's rules do not require train operators to obtain permission from control before breaking a switch seal when dealing with a fault, but they are required to obtain permission from control before moving a train with the door interlock circuit bypassed. The train operator stated that he was aware of these requirements but did not apply them as he was unaware that he had operated the TDIC switch.

63 The train operator stated that he knew he had broken a switch seal when dealing with the door fault at Finchley Road. He also stated that he was generally aware of the significance of breaking switch seals, but did not appreciate the significance when doing so on this occasion. Probable influences on the train operator's actions at this time are discussed at paragraph 79.

64 It is possible that, although the train operator knew the difference between the two switches, he implicitly associated use of the TDIC switch with all door faults. This could have occurred because his annual refresher training on dealing with faults and failures included actual operation of the TDIC switch but not actual operation of the ESDC switch (paragraph 108). It is possible that this influenced the train operator's actions especially in conjunction with other factors considered at paragraph 78.

65 **The train operator was unaware that some doors remained open when he started the train and as it travelled to West Hampstead.**

66 CCTV at Finchley Road station, and internal CCTV fitted to the train, showed doors open on the train as it departed from the platform. Although various cues were available to the train operator (paragraphs 67 to 72), he did not notice these, nor was there a warning system to prevent the train departing in this condition (paragraph 71). Furthermore, no passenger alarms were operated during the journey (paragraph 76).

Door closing

67 The train operator pressed the door-close button 19 times after the train first arrived at Finchley Road and a further eight times during the time the cab door was open (paragraph 29 and table 1). The train operator stated that he did not notice the doors were not responding to his close commands because he had become fixated on the doors not opening, and all his actions were focused on resolving that problem.

In-cab indications

68 Before starting a train, train operators are required to check the DCV lights are illuminated as confirmation that all doors are fully closed (figure 6 and paragraph 41). The train operator could not recall whether he checked the DCV lights before departing from Finchley Road, but stated that if he had seen they were not illuminated he would not have started the train. He also stated that he would have stopped the train if had he noticed that the DCV lights were not lit during the journey to West Hampstead.

69 Possible reasons why the train operator did not notice the DCV lights were unlit on the panel in front of him are:

- visibility of the DCV lights was adversely affected by sunlight when leaving Finchley Road station, an effect observed by the RAIB during testing in similar conditions (paragraph 72);
- he did not check the DCV lights because he was affected by stress caused by the unusual situation and relatively high workload he encountered at Finchley Road station (paragraph 79) and possibly because he was focused on scanning the CCTV monitor images to make sure nobody was trapped in the train doors or was in an unsafe position close to the train;
- he may have carried out his train despatch process without conscious attention, a natural occurrence with processes that are repetitive and skill-based, such as train despatch (paragraph 83); and/or
- he may have relied on the ATO system, which he believed would not let a train depart with doors open (paragraph 86).

70 Operation of the TDIC switch resulted in the TMS display screen in the driving cab displaying a message saying *'door interlock is cut out car 1'* (figure 14). However, the train operator did not notice this, probably because this screen is on the opposite side of the cab and not in his direct line of vision when looking at the track ahead of the train (figure 4). As it was an information message it was not required to be brought to his attention by the sounding of a warning tone, and did not require any acknowledgement by him.

71 On some other types of London Underground train (table 6), when the TDIC switch has been operated either a reminder sounds in the driving cab and/or the ATO start function is disabled if the train operator attempts to start the train. Such a feature was not present on the train involved in the incident at Finchley Road (paragraph 93).

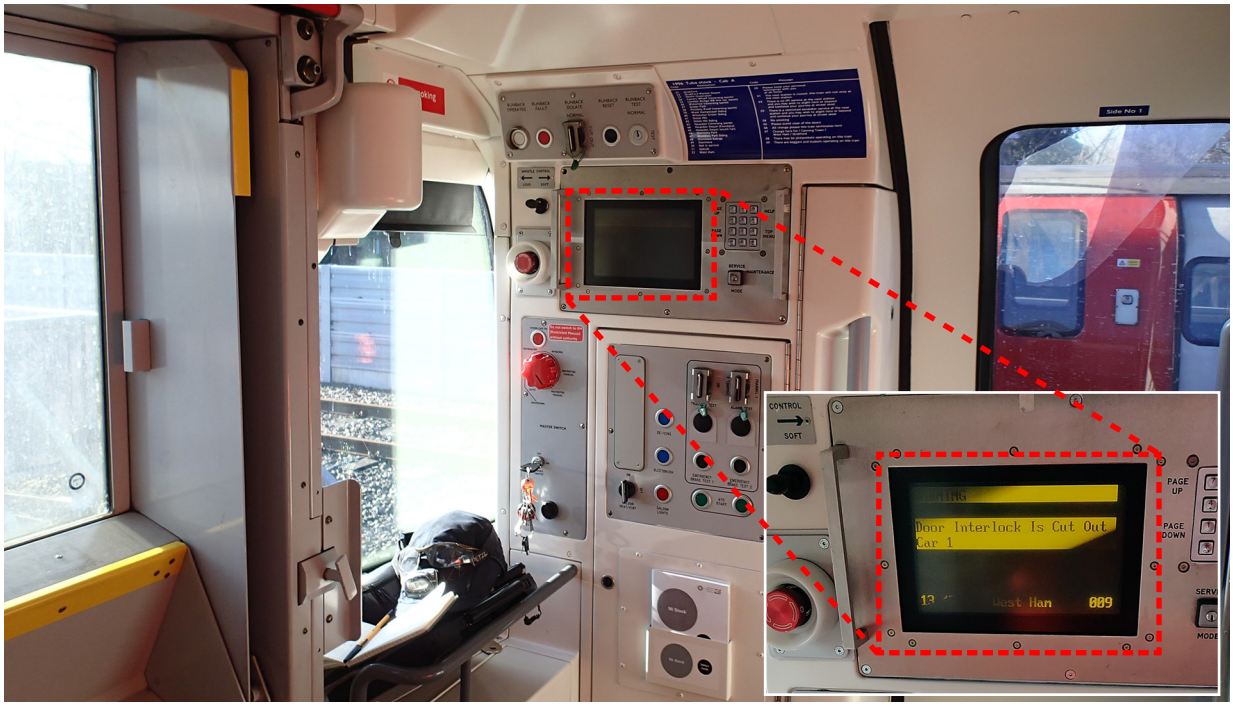

Figure 14: TMS display showing TDIC switch operated (not train involved in the incident)

In-cab CCTV

72 The train operator recalled having to use his hands to shield the in-cab CCTV monitors from sunlight when checking if it was safe to start the train, and during the time the train was leaving the platform (paragraph 14). Post-incident observations by the RAIB at a similar time of day to that of the incident showed that sun glare made it difficult to see the side of the train on the CCTV monitors (figure 15).

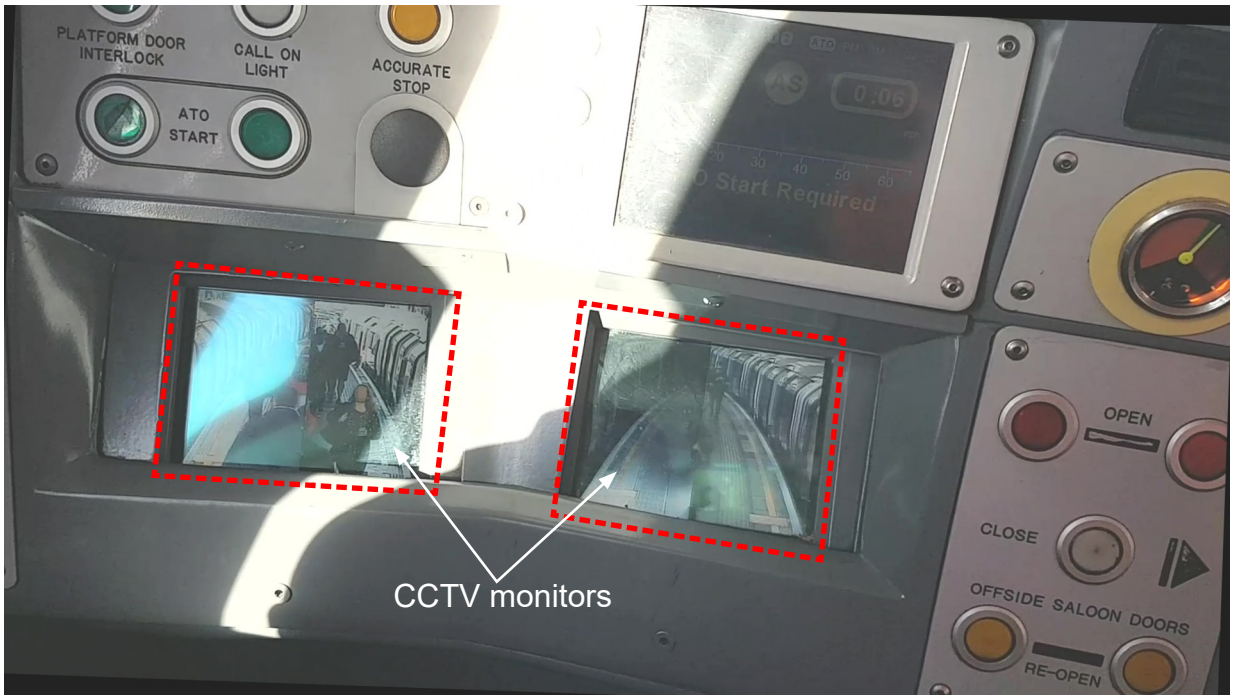

Figure 15: Sunlight shining onto the monitors (image taken with the sun in a similar position to that at the time of the incident)

73 The CCTV cameras are positioned to provide the best view along the side of the train (figure 16) so that the train operator can see if anyone is trapped in a door or in an unsafe position relative to the side of the train. There is no requirement for CCTV cameras to be aligned to directly facilitate seeing whether train doors are open.

Figure 16: In-cab CCTV monitors showing longitudinal images of the side of a train

74 On the outside of the train an orange light is provided on each car (figure 17). These illuminate when the doors on that car are open and extinguish when the associated doors are closed. Post-incident observation by the RAIB showed that it was difficult to differentiate between their lit and unlit state on the in-cab CCTV due to a combination of their recessed design and sunlight shining on them. For these reasons they were not sufficiently conspicuous to draw the train operator's attention to the fact that some doors had not closed.

Passenger intervention

75 Internal CCTV showed that several passengers were taking an interest in the open doors as the train travelled to West Hampstead, with some passengers using their phones to take photographs or videos. The CCTV also captures images that suggest at least one passenger attempted to pull a door closed.

76 The train was fitted with alarms that can be used by passengers to speak to the train operator in an emergency but none of these alarms were operated during the journey to West Hampstead. It was not until after the train arrived at West Hampstead that a passenger operated an alarm and made contact with the train operator to report what had happened (paragraph 34).

Figure 17: Door open indicator lights on outside of train

77 The most likely reasons that the emergency alarms were not used during the journey are:

- the train was not particularly busy and so there was no immediate danger to passengers as none needed to (and none were) standing very close to open doors; and
- the passengers may have believed that the train operator knew the doors were open because he had made an announcement relating to door problems before the train left Finchley Road and had explained his intention to deal with the problem at the next stop (paragraph 30).

78 **It is probable that the train operator's actions were influenced by a sudden increase in his workload, fatigue and/or low blood-sugar levels.**

79 The train operator stated that he had *'zoned out'* and made *'rushed decisions'* when dealing with the door problems at Finchley Road. These are indicators that the sudden transition from a low workload to high workload situation, fatigue and/or low blood sugar levels were probably adversely affecting his capacity to deal with the stress caused by the unusual situation and relatively high workload he encountered at Finchley Road station.

Automation and workload

80 The situation the train operator found himself in on the morning of the incident was unusual. Some doors had failed to open and there were no warnings or alarms in the driving cab to indicate to him what the cause of the problem might be. The train operator involved in this incident stated he had never experienced a situation where some, but not all, doors failed to open. The most likely reason he repeatedly pressed the door-open and close buttons is that he had rarely encountered problems with doors not opening and when he had, pressing the door-close button and then re-pressing the door-open buttons had resolved the problem.

81 This situation had arisen unexpectedly after a period of about 33 minutes (the time since he departed from Stratford) during which his required actions were limited to routine operation of train doors, observing the platform-train interface on CCTV monitors and observing the railway ahead of his train. He was then expected to apply a high level of attention and knowledge to deal with an unfamiliar situation while under the time pressures that are generally part of operating a metro train service.

82 Research[1] shows that the introduction of automation into road vehicles can significantly reduce drivers' mental workload, and that this has the potential to adversely affect drivers' attentional capacity. The same is true for the operators of ATO trains where, for the most part, ATO controls the train and train operators carry out routine activities at station stops. When faced with an unusual situation train operators may be 'out of the loop' with regard to their awareness of the current situation. This research is consistent with the Finchley Road train operator's statement that, since ATO replaced manual operation, he had needed less sleep as less concentration was needed.

83 Analysis of data from the 16 station stops made by train 305 before reaching Finchley Road showed that the train operator pressed the ATO start buttons at about the same time the door interlock was made (and thus the DCV lights illuminated) at three stations. At five stations the ATO start buttons were pressed less than a second after door interlock was achieved. LUL rules (paragraph 41) require that, after illumination of the DCV lights and before starting the train, operators must check the entire interface between the platform and train. The analysis suggests that at some stations the train operator was carrying out the despatch process without conscious attention to the task.

84 Evidence of train operators carrying out train despatch without conscious attention was also found in the RAIB's investigation of an accident where a passenger was trapped in the closed doors of a train and then dragged along as it departed from Notting Hill Gate station on LUL's Central line (RAIB report 14/2018). The investigation found that train operators are exposed to a relatively low workload, and carry out repetitive actions at stations when trains are running in ATO mode.

85 The train operator involved in the Notting Hill Gate accident was also found to have been pressing the ATO start buttons without sufficient time to check the interface between the platform and train by thoroughly scanning the in-cab CCTV monitors. Witness evidence suggested that the train operator's task can require effort to maintain attention because the ATO system reduces train operator attentional workload.

86 The potential for excessive reliance on the ATO system was also evidenced in the Finchley Road investigation which found that some train operators incorrectly believed that the ATO system would always prevent trains moving if any doors were open. Subsequent information from ASLEF (a trade union for train operators and train drivers) also supports this.

[1] Young, M., Stanton, A. (2002). Malleable Attentional Resources Theory: A New Explanation for the Effects of Mental Underload on Performance.

Lifestyle

87 It is possible that the train operator's actions were affected by fatigue which can affect concentration and decision making. There is no evidence that his rostered working hours were a factor in the Finchley Road incident, but his sleep pattern is a possible factor.

88 His normal routine when working was to get between 4½ and 6 hours sleep if possible, sometimes going to bed between 23:30 hrs and midnight, before waking up for work at 04:00 hrs. The night before the incident at Finchley Road the train operator reported having around 6 hours sleep. The train operator stated that he felt that his sleep routine did not leave him feeling tired.

89 The amount of sleep obtained by the train operator is less than the seven to eight hours of sleep that most people need each night according to 'Fatigue – a good practice guide' (dated 2012, available at www.rssb.co.uk). On rest days he would sleep for much longer, for up to 10 hours. This suggests that during the days he worked he had incurred a sleep debt, the situation when people have less than the required amount of sleep and suffer from fatigue.

90 It is also possible that the train operator's concentration was adversely affected by low blood sugar levels because he had not eaten anything for around 13 hours before the incident. This included the approximately three hours since he had woken up. This was his normal eating pattern for the shift he was working. The RAIB observed in its investigation of a derailment at Paddington on 16 June 2016 (RAIB Safety digest 05/2016), that there is research[2] showing that long periods without eating can affect people's concentration levels.

91 Shift working can be problematic with regard to managing an effective work/life balance. LUL has acknowledged this and has produced guides for its staff on this topic, arranged road shows and provided e-learning modules on its intranet. Unlike an awareness of the effects alcohol and drugs have on human performance, the effects of insufficient amounts of sleep and long periods without food may not be as well understood by all train operators because it is not compulsory for staff to seek out information related to fatigue and lifestyle. It is also the case that people may feel that their sleeping and eating patterns suit them and so do not believe that they have any effect on their performance.

92 The train operator was aware that LUL provides guidance on fatigue and managing lifestyle around shift work, but he had not sought this advice as he believed his sleep routine and lifestyle did not affect his performance at work.

Identification of underlying factors

Mitigating risk of bypassing protection provided by the door interlock system

93 **LUL had not identified that 1996 stock trains did not comply with LUL requirements for warnings related to use of the TDIC switch.**

94 The train operator at Finchley Road received no audible warning that the TDIC switch had been operated, and was able to start the train in ATO mode in this condition.

[2] RSSB publication 'Effects of Fasting on Fitness to Drive (S220)' version 1.0, dated April 2015, refers to information on the effects of long periods without eating (available at www.rssb.gov.uk)

95 A requirement for an audible warning if attempting to start with the TDIC switch operated was contained in the LUL technical specification for the 1996 stock. Clause 11.12 of the technical specification related to the train door interlock cut-out switch and required:

'Switch position 'cut-out' - Proving interlock with Driving Controls bypassed, Door Closed Visual not illuminated, Cab Audible Warning if motoring attempted'.

This requirement was then included in Clause 9 of LUL rolling stock standard RSE/STD/036 'Door control systems' issue B, dated November 1993. Clause 9 remained in force when modifications were made to the trains to permit the introduction of ATO in 2006/07.

96 Post-incident testing showed that there was no audible warning fitted to the 1996 stock in service on the Jubilee line when the Finchley Road incident occurred. The circumstances which led to this situation are unclear because:

- an LUL compliance check dated 12 June 1998 records the feature was fitted as specified;
- LUL has stated there was no intention to remove the functionality when the trains were converted to ATO, or at any other time; and
- LUL staff familiar with train operation before and after ATO conversion do not recall the feature being present.

97 The absence of an audible warning when starting a train in manual mode with the TDIC operated and doors open was a factor in an incident at Warren Street on the Victoria line in 2011 (see paragraph 117). LUL modified the train management software on the 2009 stock trains used on this line so that the train operator receives an audible warning when an attempt to start a train is made with the TDIC switch operated. However, LUL did not review its other trains to see if this modification was needed on any of them. Fitment of this feature on all LUL rolling stock types is summarised on table 6.

98 As a result of testing requested by the RAIB, and LUL's own investigation to investigate the absence of the audible warning when motoring, it was discovered that, contrary to the requirements of LUL document RSE/STD/036 and the technical specification (paragraph 95), the DCV did illuminate when all doors were closed with the TDIC operated. This did not affect events at Finchley Road because some doors were open and this would have prevented the DCV illuminating.

99 Again, the 1998 LUL compliance check stated that this required DCV functionality was fitted. Although LUL was not able to produce the ATO fitment contract details to confirm if this change was agreed at build or an omission, it believes that the ATO fitment contract did not make reference to the DCV being extinguished when the TDIC switch is cut-out.

100 There was no LUL requirement for an engineered system to prevent starting the train in ATO mode with the TDIC switch operated when the 1996 stock trains were fitted with equipment to permit ATO running between 2006 and 2008. This type of train was required to, and did, comply with LUL signalling principles document SP9.13 dated December 2005 which stated 'ATO driving with TDI [train door interlock] cut-out will be possible by the train operator after failure. PM [protected manual] and restricted speed may be enforced by procedure'.

101 On some types of London Underground train, the operator cannot start the train in ATO mode if the TDIC switch has been operated (table 6). It is possible that, if fitted to the 1996 stock, this feature would have prevented the Finchley Road incident. This is because the train operator's actions needed to move from ATO to manual control of the train would have required permission from control. This would probably have led to the train being withdrawn from service as the train operator would have explained the door problem he had encountered to control.

102 This feature (preventing an ATO start with the TDIC switch operated) was provided on the 1992 stock used on the Central line but was not included on the 1995 stock used on the Northern line or the 1996 stock used on the Jubilee line. A requirement to disable ATO start when the TDIC switch is operated is now included in LUL standard S1180 'Standard for rolling stock'.

Line	Stock	DCV lights extinguished		Audible alarm when motoring selected in manual mode		ATO start disabled if any door(s) open
		Doors open	All doors closed	All or some door(s) open	All doors closed	
Bakerloo	1972	Yes	Yes	No	No	ATO not fitted
Piccadilly	1973	Yes	No	Yes	No	ATO not fitted
Central	1992	Yes	No	No	No	Yes
Waterloo & City	1992	Yes	No	No	No	ATO not used
Northern	1995	Yes	Yes	No	No	No
Jubilee	**1996**	**Yes**	**No**	**No**	**No**	**No**
Victoria	2009	Yes	Yes	Not as built but added after Warren Street incident (paragraph 117)		Yes
Metropolitan, Hammersmith & City, Circle, and District	S[3]	Yes	Yes	Yes	Yes	Yes

Table 6: Train responses when the TDIC switch has been operated [3]

Dealing with in-service faults

103 **LUL's training of train operators did not adequately prepare them for dealing with train faults under time pressure when operating in ATO mode, a factor possibly linked to the cause of the incident.**

104 It is likely that stress caused by time pressure contributed to the train operator becoming confused between the ESDC and TDIC switches at Finchley Road (paragraphs 57 and 58).

[3] The 'S' stock trains began entering service on the Metropolitan line in 2010, the Hammersmith & City line in 2012, and the Circle and District lines in 2013.

105 Train operators receive annual refresher training to practise dealing with faults and failures. This training is delivered in a controlled environment using a train in a depot. Some of this training involves an instructor recreating faults to be diagnosed by the train operator who then takes action to deal with the fault.

106 Depot training contrasts with real-world situations where train operators deal with faults on in-service trains under time pressure, and have to make quick decisions, often relying on their memory of procedures and previous experience.

107 Simulation can be an effective way of practising scenarios under time pressure in a safe environment. LUL has two full-task simulators for its 1996 stock trains but in recent years these have only been used for trainee train operator familiarisation.

108 The depot refresher training includes dealing with situations where doors fail to open or close. Some of these situations involve operating the TDIC switch and train operators practise doing this, including breaking the seal on this switch, as part of this training. Situations where use of the ESDC switch is the appropriate response are discussed but are not practised. This is because correct functioning of the ESDC switch requires the train control systems to receive inputs indicating that the train has stopped in a platform at a position where it is safe to open the doors, and this situation is not easily re-created on the depot. LUL's existing simulators can be configured so situations of this type can be recreated.

Observations

Medical fitness

109 **LUL's process for medical examination of staff was not fully effective.**

110 A post-incident medical examination found the train operator was medically fit to drive trains at the time of the incident, and there is no evidence that medical issues affected his performance on the morning of the incident. However, he was overdue an age-related periodic medical when the incident occurred.

111 LUL standards require a medical examination by a medical professional of train operators when they reach the ages of 30, 40, 45, 50, 55, 60 and 63, and annually from 65 years of age. Between age-related periodic medicals, LUL standards require that train operators complete an annual medical self-assessment questionnaire. The questionnaire is reviewed by a manager and if necessary the train operator is referred for a medical examination.

112 Records for the train operator involved in the incident showed that he was not sent for a medical examination at age 40, and this was overdue by 4 years at the time of the incident. During that period he had completed annual medical self-assessments with no concerns raised.

113 At RAIB's request, LUL reviewed a sample of records for other train operators on the Jubilee line and found that approximately 25% were overdue the age-related periodic medical due at age 40. Subsequent analysis by LUL has identified that about 40% of its train operators and a significant proportion of station and control staff were also overdue age-related periodic medicals. LUL stated that this was caused by a change in the way age-related periodic medical examinations were booked. Age-related periodic medicals were booked by LUL's occupational health department until 2013 when responsibility was transferred to local management. LUL stated that the transfer was carried out without a sufficiently rigorous system to ensure periodic medicals were carried out.

Fatigue management

114 Some LUL train operator rosters are not in accordance with guidance to limit fatigue risk.

115 During the investigation the RAIB examined the train operator rosters, as issued by Wembley Park depot, following a process of staff consultation. The RAIB observed that in a small number of cases these rosters contained elements that are not in accordance ORR's current guidance on the management of fatigue.

116 Witness evidence suggests that it can sometimes be difficult to reconcile good fatigue management practice with the preferences of the workforce. Since LUL is aware of the need to continue to balance these competing factors, and given that most rosters reviewed by the RAIB were broadly in line with ORR guidance, the RAIB has decided to make no recommendation in this area.

Previous occurrences of a similar character

117 LUL records show that incidents of trains departing with doors open and with passengers on board are very rare. However, a dangerous incident of this type occurred on 11 July 2011 when a passenger train on the Victoria line of London Underground departed from Warren Street station with all the passenger doors open (RAIB report 13/2012). Similarities with the incident at Finchley Road include:

- the train operator did not take the train out of service in accordance with LUL's instructions;
- before starting the train from Warren Street station, the train operator disabled the train door interlock (ie operated the TDIC switch);
- the train operator's determination to minimise delays; and
- the train operator lacked the necessary competence to respond correctly when under pressure while dealing with an out-of-course event.

118 On 31 January 2018 a passenger was seriously injured when they became trapped in the closed doors of a train and then dragged along by it as it departed from Notting Hill Gate station on LUL's Central line (RAIB report 14/2018). A factor in this event similar to the Finchley Road incident was the low workload, associated with ATO, experienced by the train operator.

Summary of conclusions

Immediate cause

119 The train departed and then subsequently travelled between two stations with passenger doors open at 10 of the 28 doorways (paragraph 47).

Causal factors

120 The causal factors were:

a. some doors opened at Finchley Road station without being commanded by the train operator and none subsequently responded to him using the door open and close controls in the driving cab (paragraph 49, **Recommendation 3**);

b. the train operator did not follow LUL procedures, and bypassed the door interlock circuit that was intended to prevent trains departing with some doors open and passengers on board (paragraph 53, **Recommendation 2**);

c. the train operator was unaware that some doors remained open when he started the train and as it travelled to West Hampstead (paragraph 65, Recommendations 1 and 2, existing recommendation at paragraph 123); and

d. it is probable that the train operator's actions were influenced by a sudden increase in his workload, by fatigue and/or low blood sugar levels (paragraph 78, **Recommendations 2 and 4**, existing recommendation at paragraph 123).

Underlying factors

121 The underlying factors were:

a. LUL had not identified that 1996 stock trains did not comply with LUL requirements for warnings related to use of the TDIC switch (paragraph 93, **Recommendation 1**); and

b. LUL's training of train operators did not adequately prepare them for dealing with train faults under time pressure when operating in ATO mode, a factor possibly linked to the cause of the incident (paragraph 103, **Recommendation 2** and existing recommendation at paragraph 123).

Additional observations

122 Although not linked to the incident the RAIB observes that:

a. LUL's process for medical examination of staff was not fully effective (paragraph 109, action in progress, paragraph 132); and

b. Some LUL train operator's rosters are not in accordance with guidance intended to limit fatigue risk (paragraph 114, no recommendation, paragraph 116)

Previous RAIB recommendations relevant to this report

Passenger trapped and dragged at Notting Hill Gate station, 31 January 2018, recommendation 2

123 The above event demonstrated the risk of train operators losing attention and awareness while operating ATO trains. Recommendation 2 of the resulting RAIB report stated that LUL:

'Should support train operators of ATO trains in maintaining attention and awareness by considering and, as appropriate, implementing task-related strategies that are based on established human factors knowledge and a review of current good practice (with specific reference to RSSB[4]'s ongoing project T1133). Such strategies may include (but not be limited to) interspersing more regular periods of manual driving where feasible, introducing additional task-focused vigilance activities, or providing alerts if ATO start is attempted before the system is ready'.

124 The recommendation was made in September 2018 and ORR has not yet provided the RAIB with a formal report about progress with implementation (the legal deadline for such a progress report is one year after the publication date). Actions which LUL state have been taken are given in paragraph 131.

Train departed with doors open, Warren Street, Victoria Line, 11 July 2011, recommendations 3 and 4

125 The above event demonstrated the risk of train operators lacking the necessary competence to respond correctly when under pressure while dealing with an out-of-course event, and train operators being aware that technical advice is available so that they can effectively resolve faults and failures and avoid mistakes which could reduce safety.

126 Recommendation 3 of the resulting RAIB report stated that:

LUL's competence management arrangements for train operators should:

a) identify those who are unable to reliably and correctly respond to out-of-course events (including faults and failures); and

b) incorporate arrangements designed to eliminate or resolve the competence deficiencies identified.

In the light of the findings of this investigation, LUL should review those elements of its competence management system that relate to the ability of train operators to respond to out-of-course events, faults and failures. This should take into account:

- *how the evidence from train operators' performance in practical training and instruction is captured and dealt with by the competence management system;*
- *how the evidence from train operators' performance in incidents in service is captured and dealt with by the competence management system (paragraph 124); and*

[4] A not-for-profit body whose members are the companies making up the railway industry. The company is registered as Rail Safety and Standards Board Ltd, but trades as RSSB.

- *how LUL acts on any deficiencies identified from the above, relating to a train operator's ability to recognise and correctly respond to an out-of-course event, with the aim of eliminating any competence deficiencies identified, including how corrective action plans are developed, implemented and monitored to successful conclusion.*

LUL should implement any necessary changes to the competence management system.

127 The ORR reported to the RAIB in May 2013 that LUL had taken actions to address this recommendation and that ORR considered it to be 'implemented'. ORR's report to the RAIB included the following information provided by LUL:

'Any shortfall in Train Operator performance during training and assessment is acted upon during the training session and recorded on the CMS [competence management system] records for the individual. This CMS record provides a basis for further support and managing improvement beyond the training phase.

Evidence from incident investigation reports that recognises an error on the part of the Train Operator or demonstrates a competence or performance issue is (after validation) treated as evidence of an assessment and the relevant competence is rated and recorded on the individual's CMS record. This has the same impact as the identification of performance issues during training and can provide the basis for further training and support'.

128 Recommendation 4 of RAIB's Warren Street report stated that:

LUL should review how and in what circumstances train operators should request assistance following defects in service and implement any changes found necessary. This should include the adequacy of the competence management system and competence assessment of train operators in requesting assistance when needed. In addition:

- *train operators should be reminded of the availability of operational and technical advice when they are unable to resolve train defects and how they can obtain it; and*
- *service controllers should be reminded that they should challenge train operators if they believe them to be acting outside LUL's mandatory instructions.*

129 The ORR reported to the RAIB in May 2013 that LUL had taken actions to address this recommendation and that ORR considered it to be 'implemented'. ORR's report to the RAIB included the following information provided by LUL:

'LU will implement a multifaceted approach over a period of six months to ensure the message is communicated to Train Operators and Service Controllers from a variety of sources.

Actions will include Traffic Circular entries, changes to training material, specific messages from trainers during formal training and assessment, messages from Instructor Operators, requirements to use and demonstrate the use of documents such as Defect Handling Guides during training and assessment'.

130 The RAIB's Finchley Road investigation found no significant issues with LUL's

training of train operators in the technical aspects of fault finding, or with its competence management system. However, the Finchley Road incident showed that LUL's training had not adequately prepared the train operator to deal with faults under time pressure when operating in ATO mode (paragraph 103 and Recommendation 2).

Actions reported as already taken or in progress relevant to this report

131 LUL stated that it has carried out a human factors review of relevant research on the risks and potential solutions to train operators losing attention/awareness whilst operating a train. LUL also stated that actions from that review are being implemented on the Underground and include providing guidance for train operators to help them maintain alertness both during and between spells of driving, and working with RSSB to understand the effectiveness of tools such as the 'Guardian' product which is being used on London Trams. LUL stated it is also considering other options for the use of 'applied biometrics' tools such as wearable technologies to monitor levels of attention and awareness. LUL also stated that it has developed a training document for train operators based on RSSB research project T1133 'Evaluating prevention and mitigations to manage cognitive underload for train drivers' and will be consulting with its health and safety representatives on implementation of this.

132 LUL stated that it is considering options to resource a programme for the automated downloading and analysis of train management system data on Jubilee line trains to identify indications that maintenance is required to prevent equipment failure.

133 LUL has identified all staff that are overdue age-related periodic medicals and has stated that it has assigned extra resources in its occupational health team with enough capacity to clear the backlog by:

- prioritising individuals on a risk basis driven by role, age and length medical assessment is overdue;
- tracking of completion of assessments and outcomes; and
- taking action to prevent a recurrence of the issue.

Recommendations and learning points

Recommendations

134 The following recommendations are made[5]:

1 *The intent of this recommendation is to mitigate the risk of train operators driving a train out of a platform with one or more doors open. It is anticipated that consideration will be given to additional safeguards when the train door interlock cut-out switch is operated.*

London Underground should review the safety systems associated with control of passenger door opening and closing, including train door interlock cut-out switch operation, on its 1995 and 1996 stock trains. Where such features are inconsistent with current good practice, appropriate remedial action should be undertaken. The review should include gaining a sufficient understanding of train control systems so that potential impacts on door safety can be established (paragraphs 120c and 121a).

2 *The intent of this recommendation is for London Underground to support train operator decision-making when they are dealing with unusual faults under stressful conditions. The review could form an extension of the work London Underground is undertaking in response to Notting Hill Gate recommendation 2 (paragraph 123) but should not delay that work.*

London Underground should review and, where necessary, take action to equip its train operators with the skills, knowledge and information needed to identify and respond appropriately to faults affecting their trains. This should include consideration of the:

- use of train simulators to practise fault finding; and
- provision of documentation, such as quick reference guides, to help train operators transition effectively from a low workload scenario to an unexpected high workload scenario when there is an unusual occurrence during automatic train operation.

(paragraphs 120b, 120c, 120d and 121b)

[5] 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 and Road 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.gov.uk/raib.

3 *The intent of this recommendation is to improve the reliability of the 1996 stock trains where such unreliability has the potential to have an adverse effect on safety.*

London Underground should review options and, if appropriate, introduce procedures for routine downloading and review of data from Jubilee line train management systems, with the aim of better understanding, predicting, and preventing possible future failures with potential to impact adversely on safety (paragraph 120a).

4 *The intent of this recommendation is to improve train operators' knowledge about the effects insufficient amounts of sleep can have on performance.*

London Underground should review and, where necessary, revise its competence and fatigue risk management systems for train operators in order to increase awareness of the adverse effects on human performance from insufficient sleep and inappropriate eating patterns (paragraph 120b and 120c and 120d).

Learning points

135 The RAIB has identified the following key learning points[6]:

1 The breaking of seals and subsequent operation of cut-out switches can bypass vital safeguards. It is important that training, rules and procedures make clear the safety implications of operating sealed switches.

2 When dealing with faults, checking that the correct switches have been operated and that all necessary procedural protections are applied is more important than timekeeping.

3 Lack of sleep and excessive periods without food can adversely affect performance. It is vital that staff manage their work/life balance so that they get enough sleep, and have an eating pattern that avoids low blood sugar levels.

[6] 'Learning points' are intended to disseminate safety learning that is not covered by a recommendation. They are included in a report when the RAIB wishes to reinforce the importance of compliance with existing safety arrangements (where the RAIB has not identified management issues that justify a recommendation) and the consequences of failing to do so. They also record good practice and actions already taken by industry bodies that may have a wider application.

Appendices

Appendix A - Glossary of abbreviations and acronyms

ATO	Automatic Train Operation
CCTV	Closed-circuit television
DCV	Doors closed visual
ESDC	Emergency saloon door control switch
LUL	London Underground Limited
ORR	Office of Rail and Road
OTDR	On-train data recorder
RAIB	Rail Accident Investigation Branch
TDIC	Train doors interlock cut-out
TMCC	Train management car controller

Appendix B - Investigation details

The RAIB used the following sources of evidence in this investigation:

- information provided by witnesses
- information from the train's data recorders
- closed circuit television (CCTV) recordings taken from the train and Finchley Road station platform 2
- site photographs and observations
- driving cab rides
- weather observations at the site
- competence and training records
- LUL procedures and standards
- a review of previous RAIB investigations that had relevance to this incident.

Appendix C - Door control issues

The following additional abbreviations are used in this appendix:

TMCU - Train management control unit

TMS - Train management system

Door control circuitry

C1 The following parts of the train control system are directly relevant to understanding of the incident, in addition to the controls described in paragraphs 9 to 14 of the main report (the descriptions given in this appendix omit detail of associated equipment where this information is not essential to understanding the causes of the incident):

- A train management control unit (TMCU) is located in each of the two driving cab cars of the train. The functions of these units include passing information to other equipment and recording some events relating to the operation of train equipment.
- The train management car controller (TMCC) system comprises four TMCCs, two in the leading unit and two in the rear unit (each seven-car train comprises a three-car unit and a four-car unit). These manage various aspects of train operation with the pair in each unit acting in a master-slave relationship (paragraph C4).
- Each car has either five or six train management remote terminals (TMRTs) which control doors in that car. TMRTs are also involved in the management of other train equipment such as ventilation fans and components of the train's audio-visual passenger information system.
- The accurate stop detection system includes a train mounted antenna and a trackside antenna located close to the expected position of the train antenna when the train has stopped at the desired position alongside a platform. The system sends an accurate stop signal to other parts of the train control system when the antennae are in close proximity.

C2 The two TMCUs and four TMCCs communicate through the train data bus running the full length of the train (ie this data bus crosses the connection between the front and rear units). The accurate stop detection system provides an input to the train bus for use by the TMCUs and a separate input to the hard-wired system described in paragraph C6.

C3 The TMCU, both TMCCs and all the TMRTs in each train unit communicate through a unit data bus which carries messages between the items of equipment attached to it. This data bus links equipment within a unit but does not cross the connection between the units.

C4 The pair of TMCCs in each unit operate in a master-slave relationship with the slave providing a hot standby intended to take over the TMCC functions immediately if the master TMCC ceases to operate (eg because the master is rebooting). References to leading and rear unit TMCCs in this appendix relate to the relevant master or to the slave if this has taken over from the master at the time.

C5 The TMCCs and the TMRTs reboot (ie stop and restart) automatically under

certain fault conditions. For TMCCs, this includes being overloaded by messages received from the train and unit data buses. For the TMRT, this includes losing communication with the TMCC to which it is connected.

C6 A hard-wired connection, operating independently of the unit data bus and train data bus, uses the accurate stop detection system to initiate supply of power to every door. When an accurate stop is achieved, this system makes power available for opening the doors on the appropriate side of the train once this is commanded (paragraph C7) and until a driving cab door-close button is pushed.

C7 Door opening is normally commanded (as shown on figure C1) when a TMRT receives an instruction sent by the leading unit TMCU through the leading unit TMCC (and through the rear unit TMCC for rear unit doors) in response to the leading unit TMCU receiving signals showing:

- an accurate stop has been achieved; and
- a pair of door-open buttons have been pressed concurrently in the driving cab.

C8 As designed, the doors can also be opened if the train has not stopped close to the accurate stop positon. This allows for circumstances when the train has stopped at a platform, but not close to the accurate stop position, and the train operator has visually confirmed that all train doors are alongside a platform so the doors can be opened safely. In these circumstances operating the ESDC switch provides a hard-wired connection bypassing the accurate stop and TMCU/TMCC/TMRT control functions so that doors open if the pair of door-open buttons are pressed on the back wall panel on the platform side of the driving cab.

C9 In both the above operating scenarios, three seconds after commanding the doors to open, each door related TMRT resets relays within itself ready for the door closure sequence.

C10 If a TMRT boots or reboots, it does not enter its normal operating mode until it has communicated with the TMCC in the same train unit. Until this happens, the TMRT is in default passenger mode; this should not be confused with the intended individual opening of doors by passengers as originally fitted to the train (paragraph 18). In this condition a door will open if:

- power is available due to an accurate stop being achieved; and
- the TMRT receives a signal showing that the local door-open button has been pressed.

C11 Door closure occurs, provided the TMRT relays have been reset (paragraph C9), when the door open power is lost because the link between the accurate stop detection and door power source is cut by operation of a door-close button on either the driving cab console or driving cab back wall. This applies in normal operation and when door commands cannot be passed through the TMCCs, so the ESDC switch has been used to open the doors.

C12 Resetting the TMRT relays ready for door closing can only occur when there is communication through the unit bus between the TMRT and other parts of the train control equipment. If doors have been opened using local buttons with TMRTs in default passenger mode, the relays must be reset when communication has been established between the TMCU, TMCCs and TMRTs as the TMRTs do not resend door status information after rebooting.

C13 In most circumstances resetting these relays is achieved (even if doors are already open) by using one of the door opening procedures given in paragraphs C7 and C8. LUL is uncertain whether this is effective in all circumstances when parts of the train management system are rebooting.

Events at Finchley Road

C14 It is likely that the unusual behaviour of the train doors at Finchley Road station resulted from a loss of communication between items of train control equipment coupled with defects in some of the door-open buttons provided at passenger doorways. It is probable that communication was lost when part, or parts, of the train management system rebooted (restarted) after being overloaded by multiple fault messages generated by defective ventilation equipment and defective passenger information systems.

C15 The control system status causing the doors to behave unusually at Finchley Road station developed during the 59 seconds after the train had left the preceding station, Swiss Cottage, where the doors had behaved normally. It is possible that this control system status had existed on previous occasions but was not noticed because there was little or no overlap with the times when doors were commanded to open or close.

C16 Train equipment does not record the status of TMRTs as they reboot, enter default passenger mode, establish communication with associated TMCCs and/or then enter normal operation mode. However, it is almost certain that door opening was commanded using doorway buttons while the TMRTs were operating in default passenger mode. Train doors opening at 10 doorways, but remaining closed at 15 doorways, is consistent with the expected characteristics of TMRTs in default passenger mode and investigations by LUL have found no alternative explanation for this pattern of door opening. Default passenger mode also explains why passenger doors did not respond when the train operator pushed door-close buttons.

C17 It is also almost certain that the TMRTs entered default passenger mode because they rebooted. This is an expected behaviour of a TMRT and there is no evidence of a different cause; it is improbable that several TMRTs simultaneously developed a fault causing default passenger mode.

C18 It is probable that the TMRTs rebooted because they lost communication with the associated TMCCs. Post-incident testing by LUL found no fault with the communication buses. It is therefore probable that the TMCC system stopped communicating with the TMRTs. As doors operated unusually in both the leading and rear train units, it can be inferred that the TMCCs in both train units stopped communicating with their respective TMRTs.

C19 The status of TMCCs is not recorded so there is no definitive evidence of how these influenced events at Finchley Road. Post-incident testing by LUL found no faults with the TMCC units but did identify, from data recorded by the TMCU, that there was a large number of messages relating to train ventilation fan faults and train passenger information faults in both train units. The affected fan and information system controllers sent messages through the TMRTs unit buses and train bus to the TMCUs. These messages passed through the TMCCs which were required to process all of them to determine whether it was required to act on the message.

C20 The most likely explanation, and the only possible explanation identified by LUL for a loss of TMRT-TMCC communication, is rebooting of TMCC units due to them being overloaded by the number of fault messages. This implies that the master-slave arrangements in each train unit did not provide a near-continuous communication with the TMRTs. While there is no definitive evidence, it is possible that the number of fault messages resulted in:

- slave TMCCs not correctly implementing the process for transferring of control from master TMCCs;
- slave TMCC units rebooting shortly after taking over control; and/or
- master and slave TMCC units repeatedly exchanging control.

C21 It is not possible to be more definitive about possible problems with the master-slave arrangement as LUL was unable to provide information concerning the frequency or duration of TMCC reboots. This is because reboots are not recorded unless they take over 20 seconds and the usually correct operation of the master-slave arrangement means that reboots do not usually affect train operation.

C22 It is unlikely that the fault originated in one of the TMCUs as these record train management information and LUL reported no obvious gaps in the event logs generated by the TMCUs.

C23 The large number of train ventilation fan and passenger information system fault messages was a consequence of each fault in these systems repeatedly sending a fault message. Although LUL has sufficient information to determine that a large number of fault messages were transmitted, it cannot give more precise information as this is not recorded by the train management system.

C24 LUL has been unable to recreate the exact status of the control equipment during the Finchley Road incident, and so was unable to establish with certainty the effect of correctly following the procedures, including operation of the ESDC switch, intended to be applied by train operators dealing with doors not opening and closing when expected.

C25 Post incident testing by LUL found that some local door-open buttons were defective. Some button defects had the same effect as keeping a button permanently pushed. Other faults meant that the intended effect of pushing a button was not achieved. In default passenger mode, the first of these defects would cause the associated doors to open as soon as power was available to open them. The second type of defect meant that passengers pressing a button would not open the associated doors.

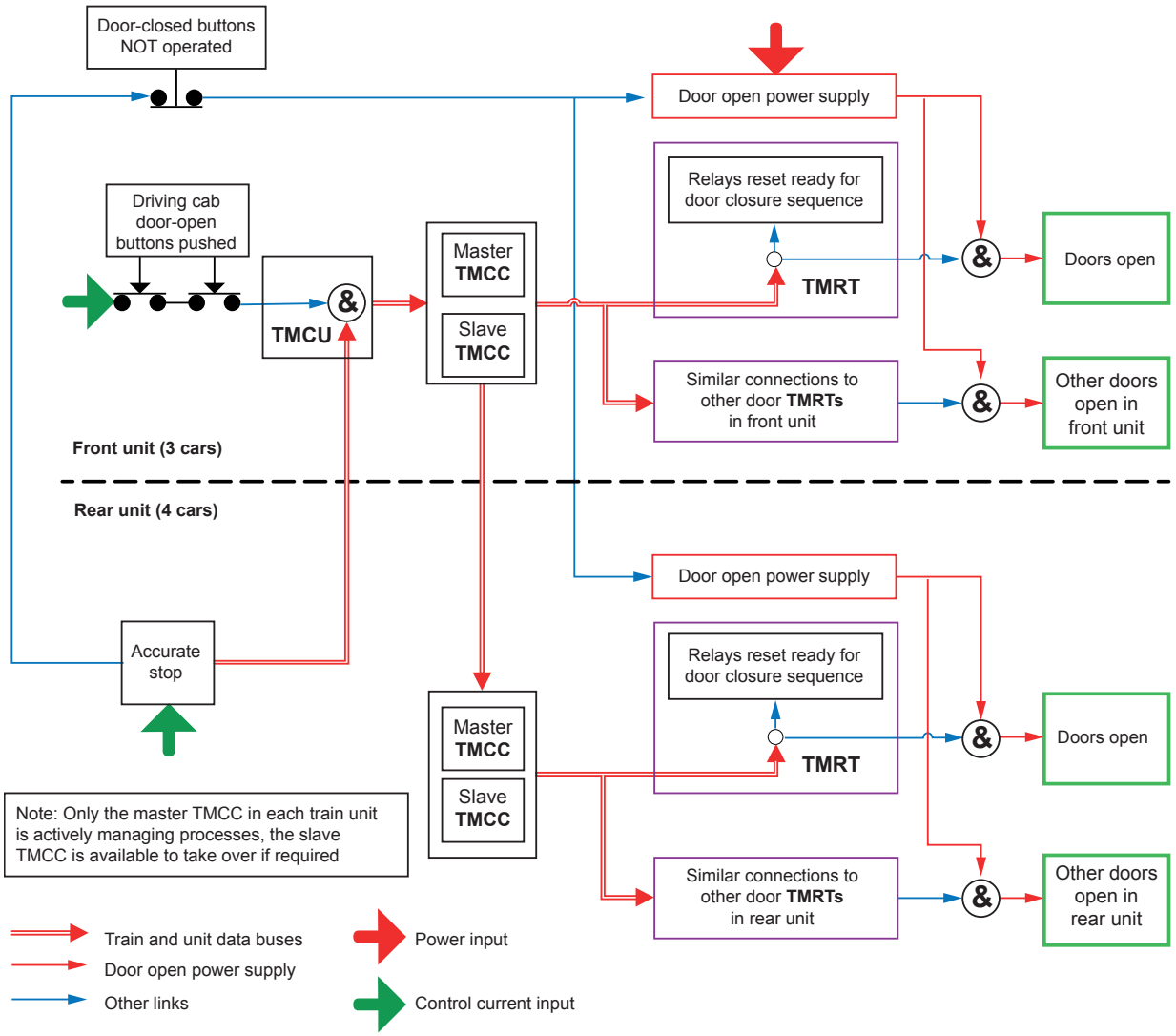

Figure C1: Door opening system, normal operation with train stopped accurately (simplified)

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This report is published by the Rail Accident Investigation Branch,
Department for Transport.

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