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MTR Adopts Improvement Measures after Lessons Learnt from Kwun Tong Line Service Disruption on 5 August 2017

The MTR Corporation submitted a report to the Government today (19 October 2017) upon the completion of the investigation into the Kwun Tong Line signalling failure incident which took place on 5 August 2017. The Executive Review Panel, which was set up by the Corporation to look into the incident, concluded that the incident was managed in a safe manner according to established procedures. During the incident, the Corporation had made its best efforts to continue to provide train service and minimise the impact on passengers despite inevitable train journey delays. The Panel also put forth recommendations for improvements after completing a thorough investigation into the cause of the signalling failure, the recovery process and customer information rendered during the incident. (See Appendix for findings of the report)

The Corporation takes the service disruption on Kwun Tong Line on 5 August very seriously and set up an Executive Review Panel on 7 August to look into the incident. The panel was chaired by Managing Director Dr Jacob Kam with other five senior members from the Corporation. An expert group with four independent external experts was also appointed to provide professional advice to the panel.

The Panel concluded that the signalling fault resulted from intermittent data loss which was due to corrosion of electrical contacts in a junction box along one of the two concurrent copper datalinks on track-side near Ngau Tau Kok Station. The corrosion was caused by water ingress through a cable entry point on the originally water-tight junction box, which eventually resulted in loss or corruption of data in Kwun Tong station interlocking area. As such, the interlocking system executed the fail-safe protocol causing all trains in the affected area to stop. Such an intermittent cable fault had never happened in the Kwun Tong Line interlocking system in the past.

Safety, which is always MTR Corporation's top priority, was maintained throughout the incident. Instead of suspending the train service to identify the root cause by checking and testing all relevant equipment, the Corporation endeavoured to maintain service to minimise the impact on passengers while working on recovery at the same time. Throughout the incident, the recovery team worked very carefully to ensure the safety of trains while proceeding with the recovery work, and that resulted in the actual total recovery time required.

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The Panel agreed with the operational principle of maintaining train service as much as possible during incidents to minimise impacts on passengers and reduce the burden on other transport modes and on road traffic, when compared to the alternative of shutting down a section of a rail line. In fact, a steady train service on the Kwun Tong Line was maintained at a frequency of four to five minute intervals from around 2:30 pm until complete resumption in the evening, which was generally able to meet passenger demand.

To reduce the risk of recurrence of any similar signalling failure incident, alongside a number of other technical recommendations, the Panel suggested to convert the concerned signal interlocking long-distance copper datalink system in Kwun Tong station interlocking area into an fibre optic system to further enhance its fault tolerance. This work has commenced and the conversion will be completed by the end of October 2017.

The Corporation is also following up on other recommendations by the Panel, including:

- To enhance passenger communications and dissemination of information during atypical situations like this incident to enable customers to better understand the changing train service patterns, including the limited service in the initial stage of an incident.

- To enhance regular maintenance of data cables including checking data integrity to ensure smooth transmission.

"While the Panel has concluded that the incident handling was in accordance with the established protocol and the network operations were safe and orderly, the MTR Corporation is committed to taking the suggested improvement actions set out in the review report in line with our continuous improvement culture," said Dr Jacob Kam. "Once again, we apologise for the inconvenience caused to passengers who were affected by the incident on 5 August."

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Executive Review Panel Report on Signal Control Failure at Kwun Tong Station Area on 5 August 2017

1. Overview

1.1 The MTR principle of recovering an incident is, first to ensure safety throughout the process, then to continue train service as much as possible, and at the same time minimise delays. This principle was consistently applied in the recovery of the signaling incident on the Kwun Tong Line (KTL) on 5 August 2017.

1.2 On that day at 1102 hrs., signal control of Kwun Tong station (KWT) interlocking area was lost. All points in the area could not be controlled or secured at both Operations Control Centre (OCC) and station level. Manual securing of points and manual train movement at low speed were required inside the area.

1.3 Signalling system incidents can be complex, and the incident on that day was unusually difficult because it was caused by an intermittent cable fault. The fault created changing symptoms through time and made fast diagnosis almost impossible. Although temporary recovery actions of the train service were completed at 1159 hrs and a steady service was achieved by 1432 hrs, the recovery team pressed on with a process of elimination testing and eventually found the fault and resumed the full signaling system capability by 2134 hrs.

1.4 Throughout the incident, train service was always maintained for the rest of KTL between Whampoa station (WHA) and Choi Hung station (CHH). Train service between CHH and Tiu Keng Leng station (TIK) took some time to be built up after the securing of points. By around 1432 hrs., train service headway on the KTL had been resumed to a steady state with headway between 4 minutes to 5 minutes. This service generally met the passenger flow demand on that day.

1.5 KTL signaling system has been maintained to a good standard. The line has experienced a stable and even slightly improving trend of signaling incident rate, even though the equipment is scheduled to be replaced in 2020.

1.6 Nevertheless, lessons learnt from this incident will help MTR improve its performance further.

2. The Executive Review Panel

2.1 On 7 August 2017, the Corporation set up an Executive Review Panel with the following terms of reference:

(a) To establish the facts and circumstances surrounding the incident and its immediate aftermath;

(b) To identify the root cause(s) and other contributory factors leading to the incident;

(c) To review the timeliness and effectiveness of the incident response and recovery processes including the initial actions taken at site and the adequacy of the relevant procedures, to identify areas for improvement;

(d) To assess the timeliness and adequacy of the information provided to the public in relation to the incident and the arrangement of train service and shuttle bus services, to identify areas for enhancement; and

(e) To review the signalling system of KTL if it is still fit-for-purpose to meet the needs of current operations in terms of functionality and failure trend.

2.2 The findings of the Review Panel are summarised as follows:

3. Train Service

3.1 The MTR principle of recovering an incident is, first to ensure safety throughout the process, then to continue train service as much as possible, and at the same time minimise delays. This principle was consistently applied in managing the train service on the incident day.

3.2 After the initial efforts of securing points on track and releasing trains which were stranded between stations, through-line service on KTL was enabled at around 1159 hrs.

3.3 During the incident 135 additional staff were deployed to the affected KTL stations (mainly CHH, Ngau Tau Kok, KWT and Yau Tong stations) to help customers.

3.4 While train service was always maintained between WHA and CHH, train service between CHH and TIK needed time to be built up after the securing of points, through the use of a safety procedure called "pilotman working"[1]. By 1432 hrs., a stable train service on the KTL had been achieved with headway at around 4 minutes to 5 minutes. The achieved train service frequency has generally met the demand on that Saturday, and it was observed that the vast majority of passengers on platforms along KTL managed to board the first or the second trains. Stations and platforms were orderly throughout the incident.

3.5 In the first hour of the incident, time was needed to secure a number of points on the track, in order to ensure safe operations of train service between CHH and TIK. As a result, only a few train passes, including moving the 3 stranded trains, were possible in the two directions of travel between CHH and TIK.

In the second hour, the train service between CHH and TIK was slightly improved as limited train passes were run in the two directions between CHH and TIK.

In the third hour, headways of 6 minutes (10 train passes) and 7.5 minutes (8 train passes) were achieved in the two directions between CHH and TIK respectively.

From 1400 hrs. onwards, train service started stabilising with an average headway at around 5 minutes. By 1432 hrs. (3½ hours after the start of the incident), a steady service with headway at 4 minutes to 5 minutes was achieved.

3.6 The longest train journey delay during the incident was 83 minutes which happened during the first 2 hours of the incident. Some passengers in the first 2 hours of the incident had to wait quite some time for a train because the service was still building up and the trains did not arrive at the various stations evenly over the first 2 hours. The Panel considers the situation inevitable at the start of a "signal control area failure" incident. It

[1] Pilotman Working is a safety procedure for multiple trains under manual operations in sequence.

is impossible to provide a normal service in such circumstances even among the best railways in the world.

> ***"One must realize the signaling system is highly complex and the engineers were under immense pressure during the recovery period and in fairness, they had already done a reasonable job of providing a slightly degraded service from around 2:30 pm onwards and this is indeed as best as any international railway operators can achieve."***
>
> - ***By External Consultant Professor S.L. Ho***

4. Handling of Stranded Trains

4.1 At the start of the incident, there were 2 trains stranded between stations, namely train T01 which had just left Lam Tin station (LAT) and T09 which was approaching Ngau Tau Kok station (NTK).

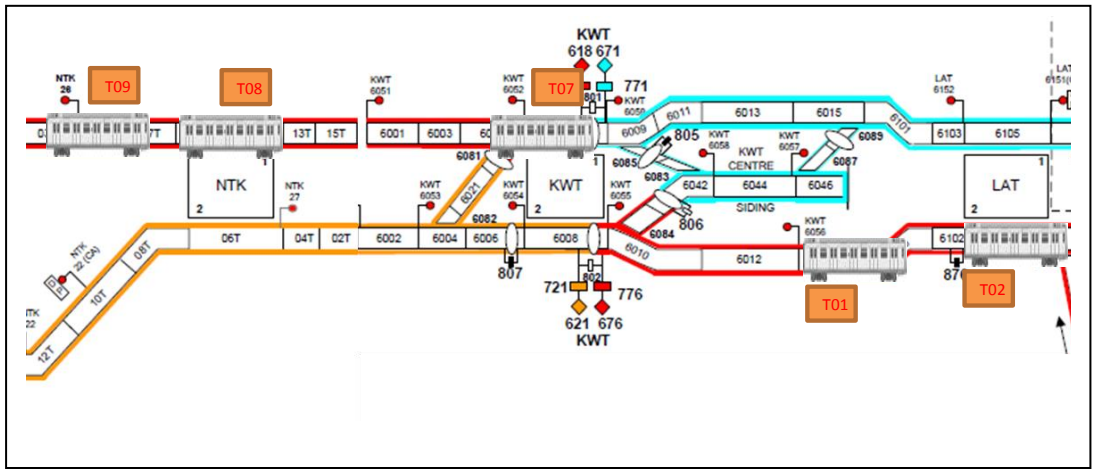

Diagram 4.1: Locations of Affected Trains
(NTK = Ngau Tau Kok station, KWT = Kwun Tong station, LAT = Lam Tin station)

4.2 By following safety procedure, NTK platform was cleared of any train after 23 minutes and T09 was moved to the platform and passengers could get off the train.

4.3 While T01 was stranded, the following train T02 was held at LAT platform automatically by the signalling system for LAT area control. After stopping for 5 minutes, T01 was manually driven to KWT platform to release the passengers. As the forward path was cleared, T02 was automatically driven by the signaling system to the next signal KWT6056 at which it became stranded. It took another 48 minutes before T02 can be moved to KWT platform following safety procedures.

4.4 It is normal practice to leave trains under automatic signaling control as far as possible because this is the best way to minimize train-running delays. With hind-sight, although this is not in the standard procedure, train T02 could have been manually held at LAT and it would not have been stranded between two stations.

4.5 ***The Panel considers that there is room for improving the procedure in releasing stranded trains and preventing additional trains from becoming stranded in incidents.***

4.6 ***The Panel also recommends that the revised procedure be included in traffic control staff's normal and refresher training. Drills and exercises should be carried out to ensure competency of all relevant staff in applying the procedure.***

4.7 There was a question on whether T02 passengers could have been detrained onto track. The Panel considered that train-to-track detrainment would have exposed the passengers to walking hazards and it was safer to keep passengers on the train, where they still had full air conditioning and lighting. Furthermore, train-to-track detrainment would have added another hour of delay to the incident based upon previous experience because it would have required passengers to walk on the track to a station and the follow-up process to ensure the track clear of the detrained passengers. It was correct not to conduct train-to-track detrainment.

5. Passenger Information

5.1 Service disruption and headway information updates were disseminated in a timely manner to customers and passengers in stations and on trains through multiple channels, including station and train public announcements, passenger information displays, Service Information Panels, website and smartphone apps (MTR Traffic News). Incident information and service updates were also proactively provided to media so as to disseminate the information to public.

5.2 In the first hour of the incident, however, the messages of "10 to 15 minutes additional journey time" and "service at 15 minute intervals" did not accurately reflect the changing condition of the service as train arrival frequency was not regular or stable at the time. The 15 minute headway was gradually achieved only in the second hour. In the beginning of an incident of this type, the service can be very limited and service patterns can vary a lot. It is therefore important that more accurate service information is conveyed to passengers for them to better understand the changing situation.

5.3 By 1432 hrs., train service had become steady and was generally meeting the demand of passenger volume. In other words, the vast majority of passengers could get onto the first or the second trains. Passengers were informed that the headway had been restored to 5 minutes, and they could have been told that temporary recovery actions had been completed, a steady service had been achieved and the service was generally meeting demand. In accordance with established protocol, a message of resumption was given at 2135 hrs. when the system was restored to be able to operate at the established timetable. As a result, the public perceived that the KTL service was disrupted for over 10 hours even though the service had been steady since 1432 hrs.

5.4 ***The Panel considers that there is room for improving passenger communication and information to cater for atypical situation of long recovery and with temporary recovery actions completed and to enable customers to understand the changing train service pattern better,***

including the limited service in the initial stage of such an incident.

6. Technical Root Cause

6.1 The root cause of the incident was an intermittent open circuit in one of the two concurrent data transmission link cables. The two link cables provide redundancy in the signaling interlocking so that signaling control will work normally as long as one cable is working. However, the intermittent open circuit did not stop data transmission in that cable completely, but rather it caused intermittent loss or corruption of data. The resulting data corruption caused the KWT area interlocking system to automatically shut down according to the fail-safe design principle.

6.2 Each of the two data links consists of a twisted pair of copper cables that run along track-side in insulated sheaths. KWT signalling interlocking is the only interlocking in the MTR network that is still using copper cables as long distance data link between equipment rooms. All the rest use fibre optics. Although new systems will use fibre optics, copper cable is a well-established technology for data transmission. The KWT copper cables were originally planned to be removed when the KTL signalling system is replaced in 2020.

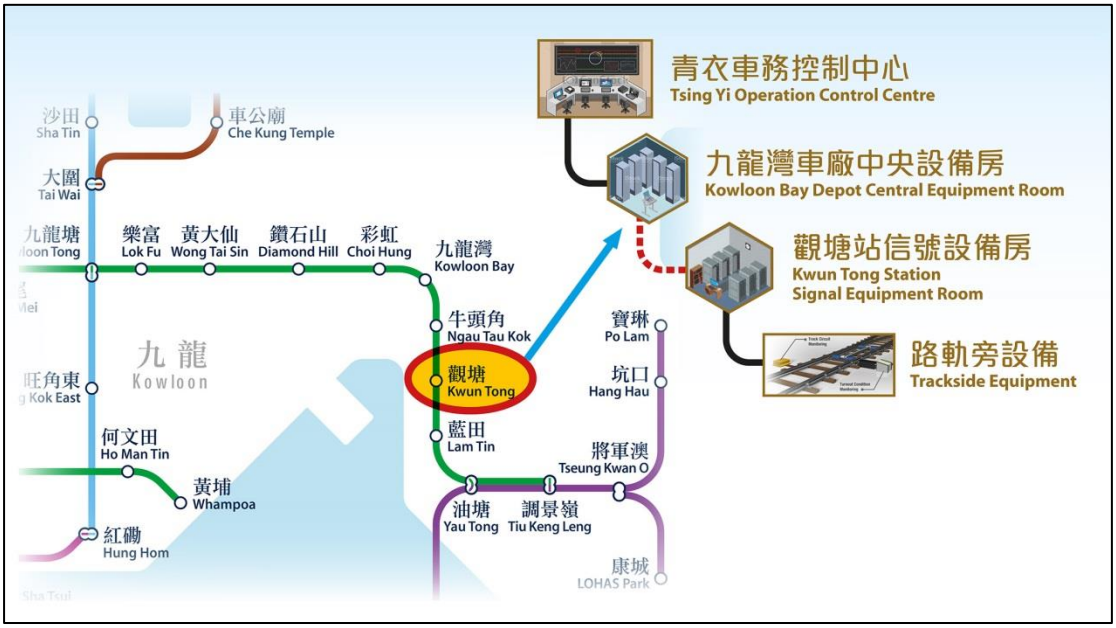

Diagram 6.1: Data transmission

6.3 The intermittent fault was due to water ingress and corrosion inside one junction box of the copper cables. The corrosion of electrical contacts coupled with train movement vibrations caused intermittent short duration open-circuits, resulting in intermittent loss or corruption of data. As the inter-locking system detected inconsistent data set, it executed the fail-safe protocol and shut down all the 3 Multiple-Processor Modules (each module is like a computer), causing all trains in the affected interlocking area to stop. Such an intermittent cable fault had never happened in the KTL interlocking system in the past.

6.4 The junction boxes were supplied with the original cables and had sufficient water proofing for track-side / outdoor environment. It appeared that in one box the water-proof seals had not been able to completely prevent water ingress, perhaps during the recent typhoons and heavy rainfall. The water ingress then led to corrosion of electrical contacts inside the boxes.

6.5 The intermittent cable fault was unusually difficult to be identified quickly. The fault produced inconsistent, changing and even conflicting symptoms which made fast diagnosis difficult in an emergency recovery, and could only be detected by using appropriate specialist equipment to study the data signal being transmitted.

6.6 Although after the enhanced maintenance recommended in the next section of this report, the copper cables would continue to be fit for use until 2020, the Panel considers that fibre optics based data transmission link can further enhance the signalling system's fault tolerance and has failure modes that are more easily detected. Work has been completed in the last few weeks to prove that the copper data links can be converted into a fibre optic system.

6.7 ***The Panel recommends to convert the KWT signal interlocking data-links into a fibre optic system before end of October 2017.***

> ***"MTR have correctly determined that the asset which failed was a Data Link Junction Box which is located along the track."***
>
> ***"As the data transmissions were interrupted intermittently rather than permanently the system was unable to tolerate the intermittent signal by switching channels and, in accordance with fail-safe design principles, the Solid State Interlocking shut down which caused all trains in the Kwun Tong area to be halted automatically."***
>
> ***"WSP agree that conversion to fibre-optic will eliminate the failure mode that caused the KTL data transmission link failure on 5/8/17."***
>
> \- ***By External Consultant WSP***

7. Effectiveness of Technical Recovery

7.1 The MTR principle of recovering an incident is, first to ensure safety throughout the process, then to continue train service as much as possible, and at the same time minimise delays. Even though the priority to keep trains running will likely prolong the total recovery time, this principle keeps passengers moving and reduces the burden on the other transport modes and on road traffic, when compared with shutting down a section of a line. Based on this principle, train service was not suspended while the technical team attempted recovery of the signalling system. The Panel considers that this principle was consistently applied in the technical recovery of the incident.

7.2 The initial loss of signal control in KWT area was the result of the fail-safe shutdown of the KWT interlocking system. 27 technical staff were deployed to respond to the incident. The interlocking system was first successfully restarted after half an hour but signal control could not be regained. In order to identify the root

cause, the technical team had to go through a systematic process of elimination by checking and testing of all relevant equipment in Central Equipment Room (CER) at Kowloon Bay Depot (KBD) and the Signalling Equipment Room (SER) at KWT.

7.3 After the completion of the temporary recovery actions at 1159 hrs. and steady train service achieved at 1432 hrs., additional checks and tests were only allowed to be conducted in limited time slots, in order not to affect the steady train service. This was consistent with the principle to keep trains running as a priority and was an important reason for the prolonged recovery time after 1432 hrs. Further tests and recovery actions after 1432 hrs. were only allowed to be done very slowly and very carefully to prevent the steady service from being disturbed.

7.4 The intermittent cable fault produced inconsistent, changing and even conflicting symptoms, which made root cause identification unusually difficult. In fact such faults could only be correctly identified by using appropriate specialist equipment to study the data signal being transmitted. Such a study takes time and is not normally done during emergency recovery. So the technical team does not normally carry or use such specialist equipment in emergency recovery. Therefore the intermittent fault could not be identified quickly and could only be identified through a process of elimination testing of each equipment.

> ***"It is a common practice to use the principle of elimination to rule out the cause of failure but it is rather unfortunate that the root cause was identified towards the end of the elimination exercise."***
>
> \- ***By External Consultant Professor S.L. Ho***

7.5 Once the root cause was identified and isolated, KWT area signal control was fully regained at 2134 hrs.

7.6 Many railways would not have continued recovery actions after the completion of temporary recovery actions at 1159 hrs. and the achievement of steady train service at 1432 hrs. In this case, the recovery team continued to work on the signaling system until the established train running timetable was restored. In fact,

on a normal Saturday afternoon, passenger volume can be well catered for even with one or two minutes increase in headway. The Panel appreciates such efforts and considers that the time taken for the work was consistent with the principle to first ensure safety and then to keep trains running as a priority.

7.7 The Panel is of the view that, had the appropriate specialist equipment been deployed, the intermittent cable fault would have been identified probably earlier during the incident (but not before 1432 hrs.). However, using such specialist equipment will take time and may prolong the recovery process unnecessarily if the actual root cause is not a data cable fault.

7.8 Therefore, ***the Panel recommends to investigate the feasibility of using appropriate specialist equipment or special methods for future fault diagnosis of such data cables, in situations that do not delay emergency recovery. Further drills should also be organised to enhance the ability to detect such intermittent cable faults.***

8. Asset Maintenance and Prevention of Failures

8.1 The data-link system was designed to detect fault (breakage) automatically, rather than relying on detection by manual inspection. The data-link cables and their junction boxes had never failed in the past. There is also a parallel redundancy for the cables. In other words, if one data cable breaks, the signalling system continues to work normally because there is another (concurrent) data cable that will continue to transmit the data.

8.2 However this incident showed that there is a new failure mode for the copper cables (that is, intermittent fault rather than complete cable breakage) that the system cannot detect. The Panel therefore considers it necessary to conduct regular manual maintenance of such data cables. A thorough check has now been completed on the current conditions of all similar main track-side copper data transmission cables and their junction boxes for long distance data transmission between equipment rooms.

"MTR revised their maintenance regime for Data Link Junction Boxes in 2002 following system modifications made upon the opening of TKL. The Junction Boxes were deemed to be "maintenance free" on the basis of redundancy and open circuit detection provision through system design.

WSP note that this approach to maintenance (sometimes termed as "risk based maintenance") can be appropriate if the risk of system failure is low, all failure modes are self-revealing and failures can be tolerated.

In light of this new failure mode (intermittent open circuit failure), the preventive maintenance regime should be revised."

\- ***By External Consultant WSP***

8.3 The Panel also believes that the best practice is to conduct a risk assessment of the data cables and review / audit the maintenance effectiveness of similar equipment, and plan regular maintenance according to their risks to train service. Regular maintenance should include checking the integrity of data transmission using specialist equipment and the general condition of the equipment. Benchmarking on how other railways maintain different data transmission cables would also help formulate the best maintenance practice.

8.4 Therefore, ***the Panel recommends that a risk assessment be conducted on the data cables and regular maintenance be planned according to their risks to train service. Regular maintenance should include checking the integrity of data transmission using appropriate specialist equipment, to ensure smooth transmission.***

8.5 After the interlocking data transmission links have been replaced by a fibre optic system, the risk will be significantly reduced.

9. Asset Conditions of KTL Signalling System

9.1 The KTL signalling system continues to meet the functional needs of train service operations. For the sub-systems that will be replaced with a new signalling system, the incident rate (incident number per million car-km) has remained stable since 2008.

9.2 Nevertheless, design for the new KTL signalling system has already begun and the existing system is on schedule to be replaced by around 2020. The data-cable problem revealed in this incident will be eliminated soon by replacing the data transmission links with a fibre optic system. Lessons learnt from this incident will also be taken into account in the design of the new signalling system.

> ***"Lessons learned from this failure can also be applied to future signalling upgrade projects as even the latest generation of signalling systems still have some components trackside which utilise junction boxes and these are not entirely maintenance-free***."
>
> - ***By External Consultant WSP***

9.3 As for signalling system replacement, there are several issues that also need to be considered.

First is the complexity of the existing system. KTL signalling is more complex than in other lines because it is made up of several signalling systems and sub-systems supplied by different suppliers. In order to reduce risk to day-to-day train service, it was considered better to build up knowledge and experience over time on how the new signalling system will interact with the existing systems, before KTL signalling could be replaced.

Second is that signalling replacement only involves the train control and train detection parts of the system, some track-related systems such as points will remain. So signalling system replacement will not eliminate incidents caused by points and still require points to be secured during a control failure incident.

Third is the potential service risk during the replacement. In order to replace the signalling system, other associated equipment, such as trains and some station equipment, need to be modified. The programme of these modifications will have to be synchronised with the signalling replacement work, otherwise significant service disruptions could result.

9.4 Asset replacement decision is not a simple decision that can be taken lightly.

9.5 Nevertheless, ***the Panel recommends that the design of the new KTL signalling system should take into account the lessons learnt from this incident. A review should also be undertaken to determine whether the conditions of existing assets require any immediate improvement such as upgrades and partial replacement before the full system replacement around 2020.***

10. Conclusions

10.1 The Review Panel has reviewed the facts and factors relevant to the root cause and recovery of the incident and concluded that:

(a) The incident was managed in a safe manner and according to established procedures.

(b) The MTR principle of recovering an incident is, first to ensure safety throughout the process, then to continue train service as much as possible, and at the same time minimise delays. This principle was consistently applied in the recovery of this incident both in train service management and in technical recovery. On the incident day, temporary recovery actions were completed at 1159 hrs. and train service became steady by 1432 hrs. (i.e. 3½ hours after the

incident outbreak) and since that time, was generally meeting the demand of passenger volume.

(c) The incident was caused by intermittent open-circuits of the copper data link in KWT signal control interlocking area. Such copper cable as long distance data link is unique among the MTR network for signal interlocking.

(d) Although with enhanced maintenance, the copper data link can continue to be used, the Corporation has proactively decided to replace the copper data link with a fibre optic system before end of October 2017.

(e) There was no sign of increasing systematic equipment failure due to ageing or obsolescence of the KTL signalling system, and this incident was considered an isolated case.

11. Recommendations

11.1 The Panel has made recommendations in the following areas in order to reduce the probability of recurrence and to improve the overall customer service and shorten the technical recovery of similar incidents in the future:

Short Term

(a) Priority should be given to releasing trains stranded between stations and preventing additional trains from becoming stranded. Practical procedures / guidelines should be provided for traffic control staff to put this into practice.

(b) The procedure / guidelines should be included in traffic control staff's normal and refresher training. Drills and exercises should be carried out to ensure competency of all relevant staff in applying the procedure.

(c) According to established procedures, train frequencies and extra train journey time are communicated to passengers and resumption of full service is announced only after full time table operations have been achieved. However, this arrangement may not be appropriate for atypical situations

of long recovery and with temporary recovery actions completed. Passenger communication and information should be enhanced for atypical situations to enable customers to understand the changing train service pattern better, including the limited service in the initial stage of such an incident.

(d) The KWT signal interlocking data links should be converted into a fibre optic system before end of October 2017.

Medium to Long Term

(a) Feasibility should be studied on the use of appropriate specialist equipment or special methods for future fault diagnosis of similar data cables, in situations that do not delay emergency recovery. Further drills should also be organised to enhance the ability to detect intermittent cable faults.

(b) A risk assessment should be conducted on the data cables and regular maintenance be planned according to their risks to train service. Regular maintenance should include checking the integrity of data transmission using appropriate specialist equipment, to ensure smooth transmission.

(c) The design of the new KTL signalling system should take into account the lessons learnt from this incident. A review should also be undertaken to determine whether the conditions of existing assets require any immediate improvement such as upgrades and partial replacement before the full system replacement around 2020.

- End of Report -