Final report RO-2013-103 and RO-2014-103: Passenger train collisions with Melling Station stop block, 15 April 2013 and 27 May 2014

Final Report

Rail inquiries RO-2013-103 and RO-2014-103

Passenger train collisions with Melling Station stop block, 15 April 2013 and 27 May 2014

Approved for publication: November 2016

Transport Accident Investigation Commission

About the Transport Accident Investigation Commission

The Transport Accident Investigation Commission (Commission) is a standing commission of inquiry and an independent Crown entity responsible for inquiring into maritime, aviation and rail accidents and incidents for New Zealand, and co-ordinating and co-operating with other accident investigation organisations overseas. The principal purpose of its inquiries is to determine the circumstances and causes of occurrences with a view to avoiding similar occurrences in the future. Its purpose is not to ascribe blame to any person or agency or to pursue (or to assist an agency to pursue) criminal, civil or regulatory action against a person or agency. The Commission carries out its purpose by informing members of the transport sector and the public, both domestically and internationally, of the lessons that can be learnt from transport accidents and incidents.

Commissioners

Chief Commissioner	Helen Cull QC (until 8 July 2016)
Deputy Chief Commissioner	Peter McKenzie, QC
Commissioner	Jane Meares
Commissioner	Stephen Davies Howard

Key Commission personnel

Chief Executive	Lois Hutchinson
Chief Investigator of Accidents	Captain Tim Burfoot
Investigator in Charge	Barry Stephenson
General Counsel	Cathryn Bridge

Email	inquiries@taic.org.nz
Web	www.taic.org.nz
Telephone	+ 64 4 473 3112 (24 hrs) or 0800 188 926
Fax	+ 64 4 499 1510
Address	Level 16, 80 The Terrace, PO Box 10 323, Wellington 6143, New Zealand

Important notes

Nature of the final report

This final report has not been prepared for the purpose of supporting any criminal, civil or regulatory action against any person or agency. The Transport Accident Investigation Commission Act 1990 makes this final report inadmissible as evidence in any proceedings with the exception of a Coroner's inquest.

Ownership of report

This report remains the intellectual property of the Transport Accident Investigation Commission.

This report may be reprinted in whole or in part without charge, provided that acknowledgement is made to the Transport Accident Investigation Commission.

Citations and referencing

Information derived from interviews during the Commission's inquiry into the occurrence is not cited in this final report. Documents that would normally be accessible to industry participants only and not discoverable under the Official Information Act 1982 have been referenced as footnotes only. Other documents referred to during the Commission's inquiry that are publicly available are cited.

Photographs, diagrams, pictures

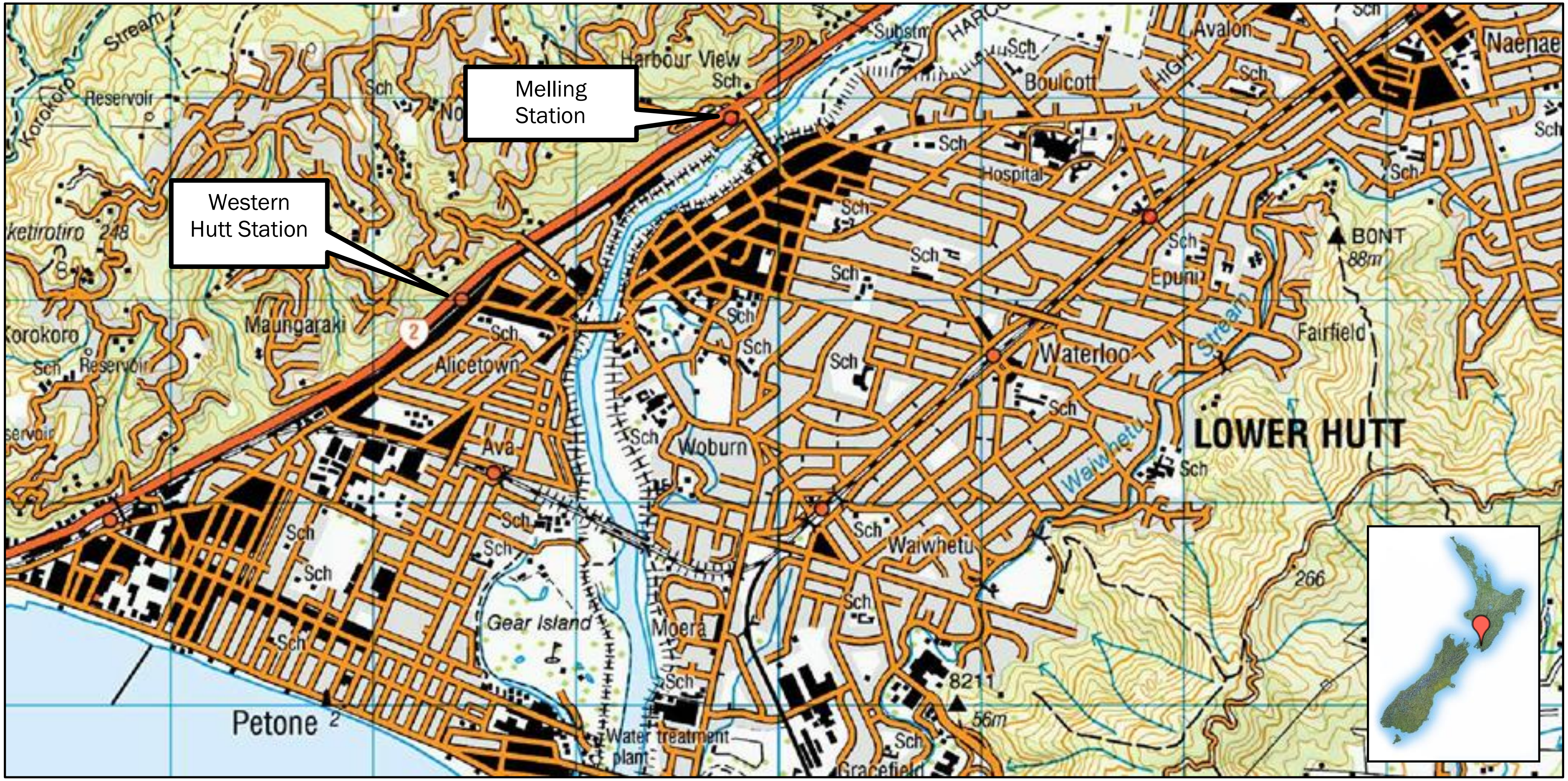
Unless otherwise specified, photographs, diagrams and pictures included in this final report are provided by, and owned by, the Commission.

Verbal probability expressions

The expressions listed in the following table are used in this report to describe the degree of probability (or likelihood) that an event happened or a condition existed in support of a hypothesis.

Terminology (adopted from the Intergovernmental Panel on Climate Change)	Likelihood of the occurrence/outcome	Equivalent terms
Virtually certain	> 99% probability of occurrence	Almost certain
Very likely	> 90% probability	Highly likely, very probable
Likely	> 66% probability	Probable
About as likely as not	33% to 66% probability	More or less likely
Unlikely	< 33% probability	Improbable
Very unlikely	< 10% probability	Highly unlikely
Exceptionally unlikely	< 1% probability	

Melling 2 train



Location of accidents

Contents

Figures

Abbreviations

Commission	Transport Accident Investigation Commission
GWRC	Greater Wellington Regional Council
km/h	kilometre(s) per hour
m	metre(s)
m/s^2	metre(s) per second per second
Melling 1 or 2	the first or second accident at Melling Station described in this report
NRSS	National Rail System Standards. A number after this refers to the standard's number in the series
NRSS/6	NRSS/6 – Engineering and Interoperability
RSSB	Rail Safety Standards Board of the United Kingdom
UK	United Kingdom

Glossary

adhesion (rail)	the degree of grip, or friction, at the rolling contact patch between the train wheel tread and the top surface of the rail head (see Appendix 4)
adhesion, low and very low	low adhesion is when the adhesion level is at 10% or less. Very low adhesion is a subset of low adhesion when the adhesion level is less than 5%
bogie	the chassis frame under a rail vehicle that holds the axles, wheels, suspension, brake equipment and electric traction motors. The Matangi cars have two double-axle bogies that are each connected to the vehicle above by a rotating joint
contact patch	the rolling contact area between a train wheel tread and the top surface of the rail head (see Appendix 4)
wheel slide	the condition where the rotational speed of the wheel is less than that corresponding to the actual linear speed of the train
wheel-slide protection	a control system that limits any applied brake force during times of reduced adhesion to utilise the maximum available adhesion and to prevent the wheels locking up. It is analogous to anti-lock braking on a motor car
wheel tread	the part of a rail wheel that runs on top of the rail (see Appendix 4)

Data summary

Vehicle particulars

Train type and number:	Matangi electrical multiple units:	
	FP/FT 4149 (Melling 1) and	
	FP/FT 4472 (Melling 2)	
Classification:	Matangi electrical multiple unit (two-car set)	
Year of manufacture:	2012	
Operator:	Tranz Metro	
Location	Melling Station, Lower Hutt	
	Melling 1	Melling 2
Date and time	15 April 2013 at 0754	27 May 2014 at 0810
Persons involved	11	12
Injuries	one minor	two minor
Damage	minor	substantial

1. Executive summary

1.1. On 15 April 2013 a two-car Matangi passenger train was operating the service from Wellington to Melling Station. As the train was slowing on the approach to Melling Station it encountered slippery track conditions, and despite the efforts of the train driver the train collided with the stop block just past the station platform. The train was damaged and three passengers received first aid, with one sustaining minor injuries. The force of the collision lifted the concrete stop block out of the ground.

1.2. Just over one year later, on 27 May 2014, the same thing happened when another two-car Matangi passenger train collided with the stop block. This time the train came to rest on top of the stop block. The concrete block split and the terminal pole for the overhead power line, mounted directly behind the stop block, was severed at ground level. The overhead contact wire drooped and momentarily touched the roof of the train, causing the electrical circuit breaker to trip for the area. The train was extensively damaged and two passengers received minor injuries.

1.3. The Transport Accident Investigation Commission (Commission) found that for both accidents dew forming on the railway track following a period of dry weather made the track slippery (referred to as low adhesion). Both trains were being driven normally but the drivers were caught unaware by the slippery track conditions.

1.4. The Commission also found that the training that drivers received for transitioning from the Ganz Mavag train type to the Matangi train type did not provide them with sufficient information in respect of the design and correct operation of the train brake and wheel-slide protection systems.

1.5. The computer-controlled train braking system is sophisticated and is fitted with two independent wheel-slide protection systems to manage braking in slippery conditions. Post-accident testing revealed that the braking systems had not been optimised for slippery track conditions when the trains were first commissioned into service.

1.6. The Commission identified a safety issue whereby the current National Rail System Standards did not require new train types to have their train brake systems tested under slippery track conditions against an appropriate standard.

1.7. The Commission also identified safety issues with the assessment of risk for trains entering terminating stations. The normal allowable train speeds left little margin for error in the event of something going wrong, and the stop block was an older type and was less effective at absorbing impact forces than its modern equivalent. Also, the pole supporting the overhead electrical traction line was directly in the path of an overrunning train.

1.8. It was of concern to the Commission that the driver of the train in the second accident was found to have cannabis in his system, although it does not believe that it was a contributory factor.

1.9. The Commission made four urgent recommendations to KiwiRail to address issues to do with risk, and two further recommendations to the NZ Transport Agency to ensure that low-adhesion braking requirements were defined in rail standards and that the brake systems on the new Auckland electric trains were optimised for low-adhesion conditions.

1.10. Actions were taken to address four of the recommendations, which were then closed before this report was published. The agencies involved have also made progress in addressing the remaining recommendations, and taken safety actions to address other safety issues identified in this report. Detail of the safety actions taken are included in sections six and seven of this report. In summary, they are:

- The train brakes were tested and optimised for slippery track conditions
- The line speed into Melling Station was reduced and the line speed at other terminal stations was reviewed and changed as appropriate

- The stop block at Melling was replaced with a shock absorbing buffer stop
- The traction power pole at Melling was relocated away from the track centreline
- Matangi drivers received further training on the Matangi brake systems
- Overhead traction power reset procedures were changed
- A low adhesion working group was formed for the Wellington area
- The procurement of a driver training simulator for Matangi trains was initiated
- The driving console in the Matangi trains was modified to alert the driver whenever the train was experiencing wheelslide activity.

1.11. Key lessons arising from this inquiry were:

- Slippery track conditions are a foreseeable risk and train braking systems must be designed, tested and optimised to provide adequate braking performance under those conditions.
- Train drivers must be adequately trained to be fully conversant with the characteristics of their train braking systems, and to drive their trains within the trains' capabilities.
- When a new train type is being commissioned and first entered into service, train operators should seek feedback from the drivers on train performance in order to identify and remedy promptly any potential performance issues.

2. Conduct of the inquiry

2.1. Notification and investigation

2.1.1. The NZ Transport Agency notified the Transport Accident Investigation Commission (the Commission) of the first accident at Melling Station soon after it had occurred on 15 April 2013. The Commission launched an inquiry under section 13(1)b of the Transport Accident Investigation Commission Act 1990, to determine the causes and circumstances of the accident, and appointed an investigator in charge. Two investigators travelled to the site that morning.

2.1.2. Evidence collected included electronic records from closed-circuit television and the train data logger, and interviews with the crew, relevant witnesses and other participants.

2.1.3. The Commission seized the train (referred to in this report as 'Melling 1') and allowed it to be partially repaired to enable a test run. A test run was conducted on 24 April 2013 on dry track. The test run replicated the train's speed into Melling Station and the driver's brake applications.

2.1.4. On 27 May 2014 a second train collided with the Melling Station stop block. The NZ Transport Agency notified the Commission of the second accident. The Commission immediately opened a new inquiry under section 13(1)b of the Transport Accident Investigation Commission Act, and appointed the same investigator in charge.

2.1.5. The investigation team attended the accident site to inspect the train, gather evidence and conduct interviews.

2.1.6. The Commission also seized the second train (referred to in this report as 'Melling 2') and allowed it to be towed to KiwiRail's Wellington maintenance depot for further examination and testing.

2.1.7. The Melling 2 train sustained significant damage to the bogie[1]. The Commission required that repairs were restricted to allow the brake operation to be tested safely during a test run while ensuring that all of the original brake components and controllers remained as they were at the time of the accident. This test run was carried out in February 2015.

Interim report

2.1.8. As the lines of inquiry for the two accidents were similar, the Commission combined the two inquiries with a view to publishing one combined report. In July 2014 the Commission published an interim report to present the facts as they were known at the time, and made four urgent recommendations to KiwiRail to address immediate safety issues.

Brake tests in low adhesion

2.1.9. One line of inquiry was the performance of the Matangi brake systems in low-adhesion[2] conditions. The Commission requested that Greater Wellington Regional Council (GWRC) (the owner) and Tranz Metro[3] (the operator) jointly carry out a full train brake test programme in controlled low-adhesion conditions.

2.1.10. GWRC agreed to fund the test programme. KiwiRail provided the project test engineer and support staff. GWRC also arranged for specialist engineers from Hyundai Rotem (the train manufacturer) and Faiveley (the brake system manufacturer) to participate.

---

[1] The bogie is the chassis frame under a rail vehicle that holds the axles, wheels, suspension, brake equipment and electric traction motors. The Matangi cars have two double-axle-bogies that are each connected to the vehicle above by a rotating joint.
[2] Adhesion is the degree of grip, or friction, at the rolling contact patch between the train wheel tread and the top surface of the rail head.
[3] Operating as a business unit of KiwiRail.

2.1.11. The Commission's investigator in charge attended two of the test runs conducted in August 2014 and December 2014. The August series was intended to establish suitable test conditions and prove the test equipment. The second series in December adopted improvements made after the first test; software adjustments were made during this series to optimise the train brake performance in low-adhesion conditions.

2.1.12. The preliminary results from the test programme raised questions for the Commission about the train's brake performance in low-adhesion conditions.

2.1.13. The Commission issued two further recommendations to the NZ Transport Agency on 26 March 2015. It also gave notice of these recommendations to Auckland Transport, which was in the process of commissioning a similar type of train at the time.

2.1.14. On 24 August 2016 the Commission approved a draft report to be sent to interested persons for comment.

2.1.15. The report was sent to 16 interested persons. Submissions were received from four interested persons.

2.1.16. The Commission has considered in detail all submissions and any changes as a result of those submissions have been included in the final report.

2.1.17. On 2 November 2016 the Commission approved the final report for publication.

2.1.18. On 24 November 2016 representatives of the GWRC appeared before the Commissioners to speak to their submission. Any changes as a result of those discussions have been included in the final report.

3. Factual information

3.1. Background

3.1.1. The Matangi train is a two-car electrical multiple unit comprising a motor car coupled to a trailer car. Each car has two bogies, with two axles on each bogie. The wheels are fixed to the connecting axle and rotate as a unit. The cars are a matched set but may be coupled to other sets to make a longer train.

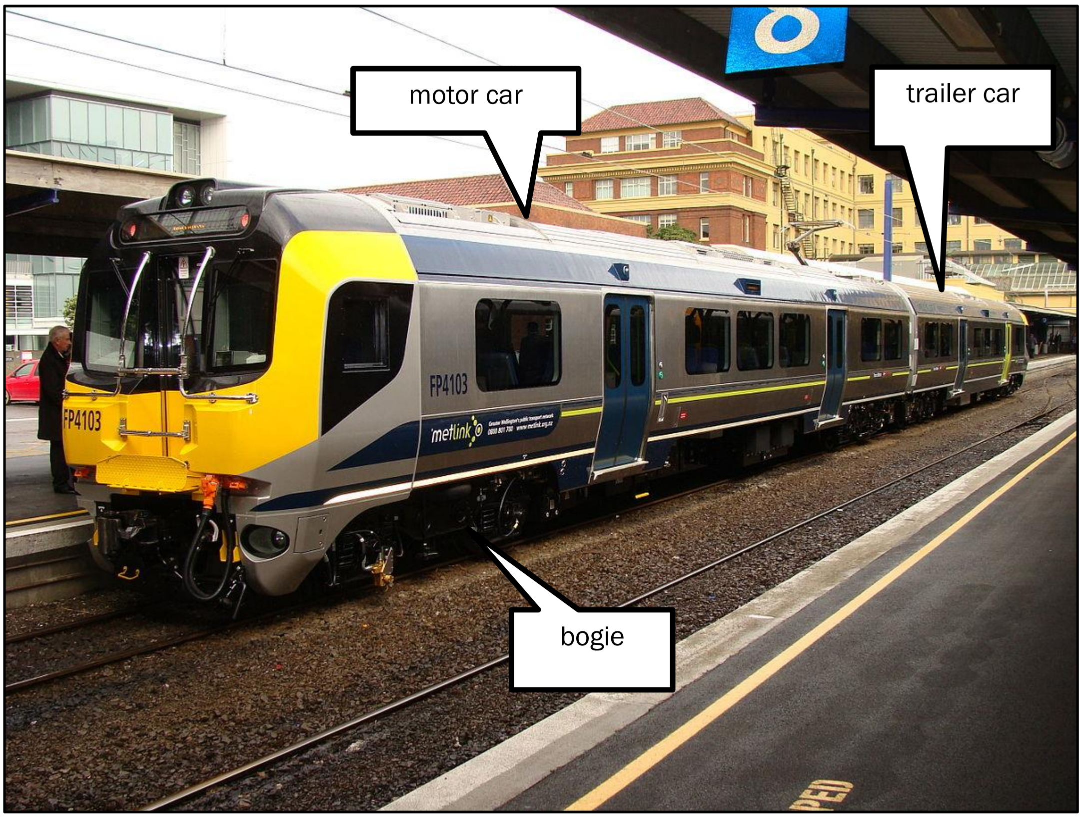


Figure 1
The Matangi two-car set
(Photo by Matthew25187 at en.wikipedia, CC BY-SA 3.0)

3.1.2. The driver normally controls the train using a single power/brake lever by moving it forward for acceleration and back for braking. The selected power or brake setting is displayed on the driver's control screen. A full-service train brake is when the power/brake position is moved to the 100% brake position. The computer-controlled brake system (see Figure 7) decides which type of brake system to use and the proportion of brake force to share between the motor car and the trailer car.

3.1.3. The brake system is designed to achieve a full service (100%) brake deceleration rate of 0.9 metres per second per second (m/s^2) and an emergency brake deceleration rate of 1.2 m/s^2 in normal conditions. It achieves normal service braking with a combination of friction and dynamic brake systems, but for emergency stops it only uses friction brakes.

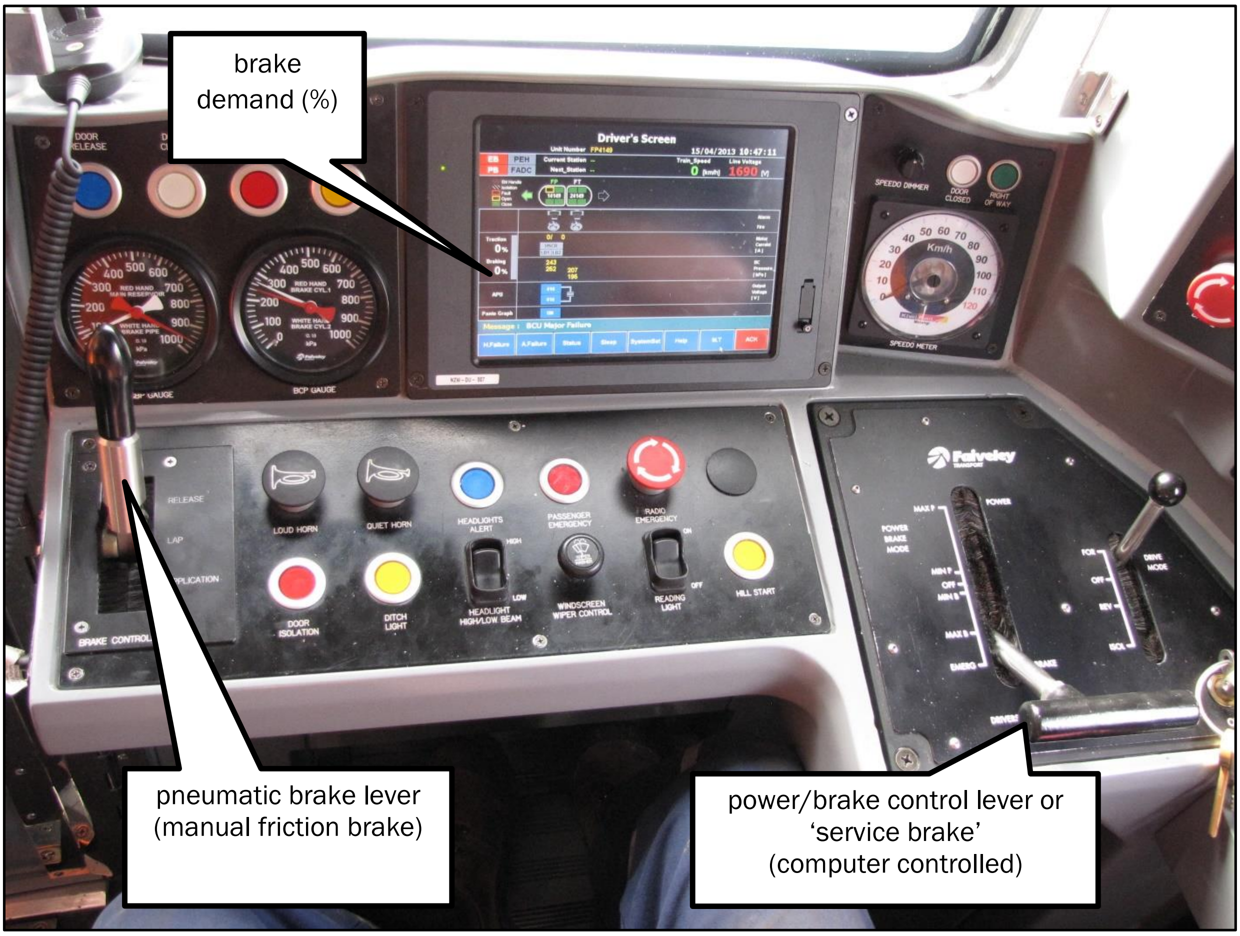


Figure 2
Driver's controls

Friction brakes

3.1.4. Friction brakes use air pressure to force a brake pad against a rotating surface to slow its rotational speed. Both cars are fitted with friction brakes, the motor car with wheel tread type and the trailer car with disc type. Tread brakes force a brake pad against the rolling surface of the wheel (the wheel tread[4]). Disc brakes are attached to the axle and the brake pads are clamped to either side of the disc by a brake caliper. The friction brakes act independently on each car of the two-car set.

Dynamic brakes

3.1.5. The motor car is also fitted with dynamic brakes, which use the magnetic fields generated in the electric traction motors to slow the wheels. This creates a braking torque that is available only when the train is in motion. The Matangi dynamic brakes act independently on each of the two motor car bogies.

3.1.6. Dynamic brakes have an advantage over friction brakes in that they result in less wear to brake components. The limitation of dynamic braking is that the train has to be moving within an acceptable speed window for it to be effective and available.

Pneumatic brakes

3.1.7. A separate, manually operated pneumatic brake lever is provided for drivers to operate the friction brakes. This also acts as a backup if the computer-controlled brake system should fail. The pneumatic brake acts equally on all axles of the train.

[4] The wheel tread is the part of a rail wheel that runs on top of the rail.

Emergency brake

3.1.8. If a driver needs to stop urgently, the power/brake lever can be moved farther back beyond the 100% position into the emergency position. This triggers the emergency brake control loop, which disables the dynamic brake and applies friction brakes to both cars in the set. The emergency brake can be initiated by several different methods and is designed to decelerate the train at a higher rate and stop in a shorter distance than it would with 100% brake.

Melling Station

3.1.9. Melling Station is a terminal station at the end of the Melling Line. The maximum line speed was 70 kilometres per hour (km/h) and the operator's procedures require that when a train passes the start of the platform it is travelling slower than 50 km/h. The end of the line had a concrete stop block to prevent trains over-running.

3.2. Narrative

Melling 1 accident

3.2.1. On 15 April 2013 a two-car Matangi train was operating the service from Wellington to Melling Station. The weather was fine but dew had formed in the area, including on the rails. The train was due to arrive at Melling Station at 0746 with a driver, train manager and nine passengers on board. As the train approached Melling Station, the driver began to apply the brake but the train did not slow as quickly as he expected.

3.2.2. When the driver realised that his train was not decelerating at the rate he required, he increased to full service brake, quickly followed by full pneumatic brake, and finally emergency brake. However, the train continued past the station platform and collided with the stop block.

3.2.3. The stop block was a partially buried concrete structure (see Figure 3). The collision forced the stop block out of the ground and the train rebounded back but remained on the rails (see Figure 4).

Figure 3
The original Melling stop block
(Matthew25187 at en.wikipedia (http://en.wikipedia.org)

Figure 4
Melling 1 impact

3.2.4. Three passengers were treated at the site. One sustained minor injuries and went to hospital for further examination.

Melling 2 accident

3.2.5. Just over one year later, on 27 May 2014, a two-car Matangi train operating from Wellington to Melling also collided with the stop block at Melling Station. The train had departed from Western Hutt Station shortly after 0808 with the driver, a train manager and 10 passengers on board and was due to arrive at Melling Station at 0809. The driver was on his second trip to Melling that morning with the same train when the accident occurred.

3.2.6. About 500 metres (m) from the stop block with minimum braking applied, the driver realised that the train was not slowing as expected. He increased to full service brake then to emergency, and then he applied full pneumatic brake. Realising that his train would collide with the stop block, he pressed the emergency brake button. He then opened the door to his driving cab and called out to warn the passengers to brace themselves, then braced himself for the collision.

3.2.7. The train collided with the concrete stop block that had been reinstalled after Melling 1 (see Figure 5 and Figure 6).

Figure 5
Melling 2 impact

3.2.8. The train came to rest on top of the stop block. The concrete block split and the terminal pole for the overhead power line, mounted directly behind the stop block, was severed at ground level. The overhead contact wire drooped and momentarily touched the roof of the train.

Figure 6
The stop block in Melling 2

3.2.9. When the live contact wire touched the train, it tripped the circuit breaker in the local electrical substation. The KiwiRail traction controller on duty at the time in the Wellington National Train Control Centre noted that the circuit breaker had tripped. The train controller called the Melling 2 driver on the radio but did not get a response, so the train controller and the traction controller agreed they would reset the circuit breaker remotely.

3.2.10. A KiwiRail employee, who had been waiting to board the train as a passenger, recognised the potential electrical hazard to the public and prevented people on the platform touching the train until the overhead wire had been made safe.

3.2.11. The train manager attended to the passengers, checked for injuries and performed first aid as required. The driver went to the rear cab to use the radio to call train control. He reported the accident, requested that the overhead power supply be made safe, and asked for emergency services to attend.

3.2.12. Emergency services attended the scene and secured the train from public access. Ambulance staff entered the train through the emergency door at the rear to attend to one passenger with minor injuries and another in shock. The passenger doors remained closed for 22 minutes after the accident, until the train was deemed safe for passengers to exit.

3.3. The drivers

3.3.1. At the time of the Melling 1 accident in 2013, the driver had 11 years' driving experience with the operator. He had converted from the Ganz Mavag type train to drive the newer Matangi type train in 2011 and had been driving them regularly since. He was tested under the operator's standard policy for the presence of drugs and alcohol and found to be clear.

3.3.2. At the time of the Melling 2 accident in 2014 that driver had 11.5 years' driving experience with the operator. He had been driving the Matangi trains since they were introduced in 2011. After the accident the driver was tested under the operator's standard policy for the presence of drugs and alcohol. He had a positive result for THC acid[5] in his urine (further information on the effects of cannabis is provided in Appendix 5).

3.4. Computer-controlled brake system

3.4.1. The Matangi brakes are controlled by computers (control units). The control units read a driver's brake demand signal and each activates an appropriate brake force depending on the speed and weight of the train at the time (see Figure 7). The control units each respond independently to the demand signal by calculating the required brake force. The control units then check how much brake force can be achieved using dynamic brakes and back off an equivalent friction brake force to ensure that dynamic is the preferred brake force.

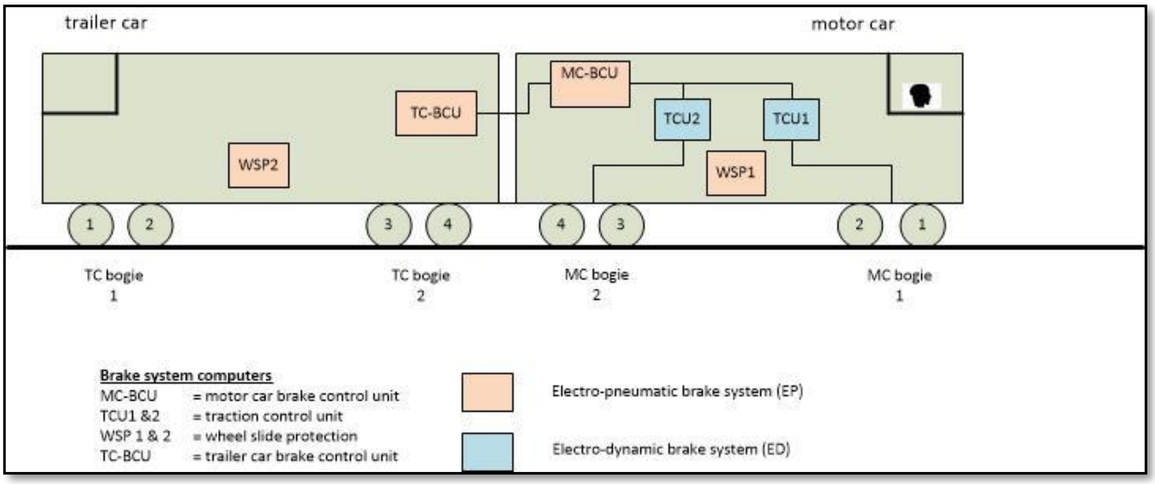


Figure 7
Brake computer control system

[5] THC acid = 11-nor-delta-9-tetrahydrocannabinol-9-carboxylic acid (or TCH-COOH).

3.4.2. As the train slows down, there is a point where dynamic braking cannot generate enough brake force. At around 14 km/h the friction brakes are blended in and dynamic brakes faded out.

3.5. Rail adhesion

3.5.1. Adhesion, in rail terminology, refers to the degree of grip, or friction, between a train wheel tread and the top surface of the rail head. Adhesion is the same as the friction coefficient but expressed as a percentage. The normal range for adhesion on rail is between 12% and 40% (see Appendix 4 for more information on adhesion).

3.5.2. Any brake application to a wheel will slow its rotating speed, which is transferred through the contact patch[6] between the wheel and the rail as a decelerating brake force. If the brake force is greater than the maximum adhesion force possible in the conditions, the wheel will begin to slide[7]. The effects of low adhesion upon a train are that the wheels may slide under braking and stopping distances will be longer.

3.5.3. The Matangi procurement specification required the brake system designer to nominate the minimum adhesion level that its equipment would need to achieve the specified deceleration rates. The nominated levels were 9.6% adhesion for full service braking and 14.2% adhesion for emergency braking.

3.5.4. Low adhesion as described in this report is when the adhesion is 10% or less. A subset of this condition is that when the adhesion is under 5% it can be termed very low adhesion. Low adhesion is an operational risk for train operators, while the very low adhesion condition is an important consideration for equipment designers. Any change to the interface between the rail and the wheel, such as the presence of water, leaves or grease, may affect the adhesion.

3.5.5. The most common cause of low adhesion is when a light layer of moisture forms or collects on the top of the rail. This may be caused by morning dew, light rain or mist. When the moisture combines with other contaminants normally found on a rail, such as dirt, rust, brake dust or solid particles of air pollutants, it can form a slurry that acts as a lubricant. In heavy rain this slurry tends to wash off the rail top and thus low adhesion becomes less of a problem.

3.6. Wheel-slide protection system

3.6.1. If a wheel starts to slide while a train is braking, its ability to apply an effective braking force through the contact patch is reduced. However, a small amount of controlled wheel slide can optimise the brake force. A wheel-slide protection[8] system allows a braked train wheel to rotate up to 20% slower than the train speed to achieve the most effective braking force in low-adhesion conditions. However, the actual train speed is not usually measured by these systems. Instead, it relies on a software-derived value analogous to the train speed called the ‘reference speed’. The system will override the brake force applied by the driver to keep the wheel speed within the 20% band below the reference speed. The Matangi has two types of wheel-slide protection system.

3.6.2. One wheel-slide protection system is a software application within another controller. It resides in the two traction control units (see Figure 7) and is effective only when dynamic braking is in use. The other wheel-slide protection system is a dedicated, stand-alone, computerised control unit that only works with the pneumatic friction brakes. A system of this type is fitted to both the motor and the trailer cars. It continuously monitors for wheel slide and operates whenever wheel slide is detected while the friction brakes are in use. This wheel-slide protection system is disabled when the train speed drops below 5 km/h.

---

[6] The contact patch is the rolling contact area between a train wheel tread and the top surface of the rail head.

[7] Wheel slide is a condition where the rotational speed of a wheel is less than that corresponding to the actual linear speed of the train.

[8] Wheel-slide protection is a control system that limits any applied brake force during times of reduced adhesion to utilise the maximum available adhesion and to prevent the wheels locking up. It is analogous to anti-lock braking on a motor car.

3.7. Similar accidents

England

3.7.1. In 2005 the Rail Accident Investigation Branch in England investigated a series of low-adhesion-related events that occurred in 2004 and 2005 (RAIB, 2005). The investigation identified two key points that were relevant to New Zealand. One was that operators used past events to predict low adhesion rather than just monitoring current conditions or risk. The second point was that the train operating companies did not understand the characteristics of their new trains. That lack of understanding led to inadequate briefing of drivers and suboptimal performance of the wheel-slide protection systems.

3.7.2. The report also highlighted: a lack of industry knowledge on the cause of low adhesion; a lack of test procedures to optimise the performance of whole-train braking systems with wheel-slide protection; and that further research was required to find the optimum set-up parameters for wheel-slide protection systems.

Melbourne, Australia

3.7.3. In Melbourne a series of incidents occurred in 2009 in which trains failed to brake effectively and overran platforms. The Office of the Chief Investigator Transport Safety investigated (OCITS, 2009) and found several contributory factors. The listed contributory factors were:

- moisture on the rail caused low-adhesion conditions
- the Nexas trains' braking system response to a wheel-slide event
- the Nexas trains did not have tread brakes, which could have otherwise helped to clean the wheel tread surface and improved braking
- the train's very good dry-track braking performance may have raised drivers' expectations in low-adhesion conditions
- drivers did not have a sufficient depth of understanding of how the Nexas braking system worked or specific guidance on operational procedures when encountering low adhesion
- the network risk management of low-adhesion conditions was inadequate at the time
- low-adhesion braking performance requirements were not adequately defined in the procurement specifications nor verified in acceptance tests.

Queensland, Australia

3.7.4. In 2013 a Queensland Rail passenger train failed to stop at a platform and collided with the end-of-line buffer stop. The train rode up over the buffer stop and onto the platform, where it flattened the mast for the overhead power line and came to rest inside the station building. The train had encountered low-adhesion conditions and the driver's actions were not contributory. The Australian Transport Safety Bureau's report into the accident listed the main contributing factor as the operator's inadequate management of low-adhesion risk (ATSB, 2013).

4. Analysis

4.1. Introduction

4.1.1. Operating trains in conditions of low rail adhesion is a predictable risk applicable to any rail system. The causes of low adhesion may vary from one country, region or town to the next, but the effect is the same: braking in low-adhesion conditions will increase the distance required to stop a train.

4.1.2. We know that low rail-adhesion conditions existed in both of the Melling accidents because wheel-slide protection activities were recorded by the train data loggers. However, the exact locations of any low-adhesion area(s), the extent of each area or areas, and the actual levels of low adhesion present at the time were not able to be determined.

4.1.3. There was nothing in the condition of the train wheels or the profile of the rail that would have adversely affected the wheel-to-rail contact patch.

4.1.4. The driver of the Melling 2 train tested positive for the presence of cannabis metabolites in his urine. The investigation was unable to establish whether his performance on the day was impaired by the effects of cannabis. However, the use of performance-impairing substances by train drivers is a significant safety issue.

4.1.5. As the following analysis shows, a factor contributing to each accident was that the train braking system did not perform as well as it could have in the low-adhesion conditions.

4.1.6. A key safety issue was that the National Rail System Standards (NRSS) did not require the Matangi braking system to be tested under slippery track conditions against an appropriate standard. Consequently the train brake system had not been optimised for low-adhesion conditions.

4.1.7. The analysis discusses what happened in each case leading up to the collision.

4.1.8. Consideration is also given to: the performance of the train braking system; driver training in respect of the differences between the Ganz Mavag and Matangi braking systems; and the management of risk to trains operating into terminating stations, which had not kept pace with industry changes.

4.2. Interpretation of evidence

Melling 1

4.2.1. The driver of the Melling 1 train had braked smoothly down to 47 km/h by the time his train reached the start of the platform. This was below the maximum speed of 50 km/h. When he increased the brake demand from 31% to 50% the wheels lost adhesion and began to slide. The dynamic brakes in the motor car were the only brakes in use at the time and the traction control units attempted to control the wheel slide. The train was about 52 m from the stop block and it would travel that distance in about six seconds.

4.2.2. The driver applied full service brake, then full pneumatic brake[9], followed by the emergency brake. The computer-controlled brake system responded by disabling the dynamic brakes. Then it increased the friction brake force on both the motor car and the trailer. As the friction brake force increased, the wheels continued to slide. The applied brake force was limited by the wheel-slide protection system while it attempted to optimise the train braking force. The train braking system was unable to apply an effective brake force in the time available. The train collided with the stop block at 0754 at an estimated speed of 25 km/h.

4.2.3. The speeds and brake actions are presented graphically in Appendix 1.

[9] Applying full pneumatic brake is effectively applying emergency brake.

Melling 2

4.2.4. The Melling 2 driver started decelerating his train 1.2 kilometres from the Melling Station stop block by selecting 'off' with the power/brake control lever. He increased the brake to 23% then reduced it to 18% when the train was about 525 m from the stop block. At 430 m out from the stop block, the wheels started to slide. The train was travelling at 58 km/h and the computer-controlled braking system was using dynamic brakes only. The traction control units were unable to control the wheel slide within three seconds, so the computer-controlled brake system disabled the dynamic brakes and increased the friction brake force in the motor car.

4.2.5. The driver had also realised that the train was not slowing at the rate he expected, so he increased brake demand to 50%, and then to 100%. The computer-controlled brake system responded by increasing the friction brake force in the trailer car to about 75%, which caused the trailer car wheels to slide also. Four seconds later the driver applied full pneumatic brake, followed by emergency brake.

4.2.6. After the dynamic brakes were disabled, the wheel-slide protection units fluctuated the friction brake force in both cars in an attempt to control the slide until the train hit the stop block at an estimated speed of 35 km/h. The wheel-slide protection systems were unable to regain an effective rate of deceleration over the last 430 m (see Appendix 1 for distances and speeds).

4.2.7. The driver of the Melling 2 train tested positive for cannabis, which is of concern. The Commission has included substance use on its 'watch list' and encourages regulators and operators to put measures in place to prevent substance impairment by persons in safety-critical roles. It was not possible to determine whether the driver was impaired at the time of the accident.

4.2.8. Although cannabis impairment reduces with time since exposure it affects people differently and is known to impair the executive cognitive function of information processing. Other executive functions affected are planning, decision-making, risk taking, and working memory. All of these functions are crucial for a train driver to operate safely (see Appendix 5 for more details).

Conditions common to both accidents

4.2.9. Both drivers were handling their trains in a normal way. They approached Melling Station within the speed limit for the line and they were on target to reduce the train speed to less than 50 km/h by the time they reached the start of the platform.

4.2.10. Both drivers said that they had been alert and focused upon the task and not distracted. They had had light duty schedules with adequate periods of rest in the days leading up to their respective accidents. Cell phone records proved that the drivers were not engaged in text or voice communications at the time. Therefore, fatigue and distraction were very unlikely to have been factors in either accident.

4.2.11. The train event recorders showed that the train wheel-slide protection system activated in both accidents, meaning that low adhesion was a common factor.

4.2.12. Both trains were repaired sufficiently for the brakes to be tested on the track. Repairs were limited to facilitate a safe test run but all brake equipment and brake-controller software were kept as they originally were during the accidents. Test runs were conducted by KiwiRail engineers on dry track around the Wellington rail network, with a Commission observer on board. Several brake test runs from a steady speed to a full stop were also conducted using various combinations of brake selection, pneumatic brake and emergency brake.

4.2.13. These test runs proved that the train brakes were working on both trains at the time of the accidents, and that each train conformed to the NRSS standard for stopping distances on dry track.

4.2.14. The Commission engaged MetService to analyse data on the weather conditions preceding both accidents. They concluded that in both cases dew was likely to have formed on the track and that the weather conditions preceding each accident had been dry for several days. These were the ideal circumstances for low-adhesion conditions to exist.

4.2.15. Several dry days preceding the accidents would have allowed a layer of natural deposits to form on the top of the rail, which was then followed by the formation of dew. The resulting mixture would have created a low-adhesion layer between the rail and the train wheels.

4.3. Management of infrastructure risk at terminating stations

The line speed limit

4.3.1. The maximum line speed for approaching Melling Station was 70 km/h. Drivers were taught to aim to have their train speeds at below 50 km/h by the time the trains reached the beginning of the platform. The line speed is set depending on the geometry of the track. From a risk perspective, Melling is a terminating station, meaning the consequences of overrunning the platform are much higher than at non-terminating stations. The same applies to the target speed for when the train reaches the start of the platform. Any train malfunction, low track adhesion or underperformance of the train braking system risks the train colliding with the stop block.

4.3.2. The Commission recommended that KiwiRail reassess the speed limit for trains approaching Melling Station, and that it also reassess the speed limit for trains approaching other terminating stations on the rail network. KiwiRail has since accepted these recommendations and addressed the safety issue.

The stop block

4.3.3. The concrete stop block had been installed in 1954. It lacked the impact-absorbing qualities of more modern stop blocks. The less effective they are, the greater the damage to the train and its occupants, as both these collisions demonstrated. The Commission recommended that KiwiRail replace the concrete stop block with a more appropriate shock-absorbing system similar to the type being installed in Auckland at the time. KiwiRail accepted this recommendation and replaced the stop block.

The overhead power

4.3.4. There were two issues with the overhead traction power system. Firstly, the terminal pole was hit by the Melling 2 train because it was directly in the path of the train when it collided with and overran the stop block. The force of the collision severed the pole, causing the live overhead wire to droop and contact the train.

4.3.5. The Commission recommended that KiwiRail relocate the terminal pole out of line with a direct overrun. This has since been completed with a new cantilevered pole mounted off to one side of the rail centreline and the safety recommendation has been closed.

4.3.6. When the contact wire drooped and touched the train, it tripped the electrical protection system, which led to the second issue. The traction controller at the Wellington National Train Control Centre reset the power before the driver was able to warn train control of the accident. The Commission raised with KiwiRail the risk of promptly resetting the overhead power without first establishing the reason for the system tripping.

4.3.7. After two further incidents KiwiRail submitted to the Commission in December 2014 that it had accepted its concerns about promptly resetting the overhead power after a protection trip. KiwiRail then issued an internal memo to change its operating procedures. Based on this action the Commission did not issue a safety recommendation.

Findings

1. It is very likely that for both collisions with the stop block at Melling Station, an extended period of dry weather combined with the formation of dew on the rail resulted in a condition of low rail adhesion along the approach to the station.
2. It was not possible to determine whether the driver of the Melling 2 train was impaired by cannabis. However, the fact that he had cannabis in his system is a serious safety issue.
3. Both trains were travelling at a normal speed of approach to Melling Station and both drivers applied a normal braking technique during the approach.
4. The operating risk and potential consequences of a train overrunning the platform at Melling Station and colliding with the stop block had not been adequately considered. No special speed restriction for the approach had been set; the stop block was an older and less effective design than its modern equivalent; and the pole carrying the overhead traction power line was placed directly behind the stop block where it was prone to damage.

4.4. Train brake performance

Brake performance expectations

4.4.1. Appendix 2 demonstrates the best theoretical stopping distance for a Matangi train in low-adhesion conditions. It assumes that the wheel-slide protection systems operate perfectly to control the wheel creep and allow the maximum brake effort to be applied in the conditions. The calculation shows that a train with a typical passenger load for Melling could decelerate at 0.49 m/s^2 to stop in 197 m from 50 km/h using full service brake in low-adhesion conditions (at 5%).

4.4.2. In the Melling 2 accident (see details in Appendix 1) the train managed to decelerate at 0.3 m/s^2 over the first 251 m, reducing to 0.015 m/s^2 over the remaining 179 m, and only slow by 23 km/h but not stop in the total distance of 430 m. This comparison between theoretical and actual brake performance indicated that either the adhesion was much less than 5% or there was a performance issue with the train brakes in low-adhesion conditions, or that there was a combination of both factors.

4.4.3. The train commissioning tests conducted by the manufacturer established that the train braking system performed to the GWRC procurement specification. These tests included extensive test runs with various combinations of brake application and some with simulated low-adhesion conditions. The overall requirement was that the train complied with NRSS/6 – Engineering Interoperability Standard, Version 1 (NRSS/6) to stop within 460 m from a speed of 100 km/h in all normal climatic conditions. Testing proved that the train met the NRSS/6 stopping distance requirements.

4.4.4. The commissioning test specification did not require the train braking and wheel-slide protection systems to be tested in controlled low-adhesion conditions in accordance with an internationally recognised standard[10], nor was it required by any other authority.

4.4.5. To investigate the performance of the brake system, GWRC agreed to conduct a series of brake tests in low-adhesion conditions and measure the performance of the Matangi brake system.

Low-adhesion brake test programme

4.4.6. The tests proved that in low-adhesion conditions the current configuration of the computer-controlled brake system did not perform as well as it could have. Several opportunities for improving the train brake performance were identified and trialled. These included:

[10] For example, UIC 541-05.

- reducing the initial amount of available dynamic brake effort
- reducing subsequent available dynamic brake effort after each wheel-slide control attempt
- improving the trailer car friction brake behaviour during wheel slide with dynamic brakes
- optimising the wheel-slide control in the motor car
- improving the handover between dynamic and friction brake controllers
- improving the interaction of automatic brakes with the manual pneumatic brakes.

The system was reconfigured and further trials were conducted.

4.4.7. As a result of the test programme, GWRC initiated corrective actions to improve the low-adhesion brake performance and approved software changes. The first software upgrade was rolled out across the Matangi fleet in 2015.

4.4.8. The test programme raised a further concern that the wheel-slide protection system for the friction brakes was not performing in accordance with the UIC 541-05 standard[11]. GWRC arranged for the brake manufacturer to conduct a more rigorous test of the wheel-slide protection units in a test facility in Italy. This resulted in a further software upgrade to improve the performance of the friction brake wheel-slide protection system in low-adhesion conditions. This software upgrade was rolled out across the fleet in mid-2016.

4.4.9. Following the testing programme and the software changes to the train brake system, the Matangi train brake performance in low-adhesion conditions was noticeably improved.

4.4.10. However, there are too many variables, unknowns and possible scenarios to draw any definitive conclusions on whether the trains would have stopped before the stop blocks if these improvements had been made when the trains were commissioned. For example:

- the dew suspected of causing the low adhesion evaporated soon after the events, so the extent and level of low adhesion could not be measured
- the method of measuring low adhesion is subject to variability and the result may differ from the actual adhesion experienced by a train
- the control inputs from the drivers could vary depending upon circumstances at the time, such as: their choice of speed and brake selections; their knowledge about how the brakes worked; and the response they had each experienced with the brakes during the accidents.

New Zealand standards for train brakes

4.4.11. It is concerning that the brake performance of a new and modern commuter train was only made to comply with the basic requirements of NRSS/6. The standard is silent on: low-adhesion brake performance; wheel-slide prevention systems; full train brake performance across different braking systems; and reference to appropriate international standards.

4.4.12. Although the selected train brake equipment had the capability to perform well in low-adhesion conditions, the brake performance specifications did not require it to be verified. Therefore, the system was not set up for optimum performance. The current trend in Europe is to test train brakes to local standards[12], with a complete train as a fully integrated brake system. These standards include the verification of wheel-slide protection systems in controlled low-adhesion conditions and the optimal integration of dynamic and friction brakes.

4.4.13. The NRSS was originally intended to provide an interoperability framework for rail participants to meet when wishing to operate on the rail network. It is still the only formal set of rail standards available in New Zealand.

---

[11] UIC is the Ünion Internationale Des Chemins De Fer"(International Union of Railways)

[12] For example in UK; BS EN 15595:2009 and RSSB GM/GN2695.

4.4.14. In 2010 the Commission issued three safety recommendations to the Secretary for Transport to address safety issues relating to the status of the NRSS. As a result of the Melling accidents the Commission issued a new recommendation to the NZ Transport Agency in 2015 to review the NRSS to ensure that low-adhesion braking requirements were incorporated into the standards and that they were applicable to all trains intended to operate on the National Rail System. The Commission now has a total of seven open safety recommendations targeting changes to the NRSS. Three are to the Secretary of Transport and four to the NZ Transport Agency.

4.4.15. The NZ Transport Agency is currently addressing these recommendations by undertaking an independent review to establish an appropriate rail regulatory framework for the future. In light of this review the Commission makes no new recommendations on this safety issue.

4.5. Driver training

4.5.1. The Matangi driver conversion training suggested that drivers consider the computer-controlled brake system as a 'black box' that performed better than the braking system in the older Ganz-Mavag trains. This suggestion was reinforced to the drivers when they experienced the Matangi train's effective brakes on dry track.

4.5.2. Critical information describing how the computer-controlled brake system operated was not provided in the conversion course material or in the Train Crew Manual. Several drivers were interviewed about their understanding of how the computer-controlled braking system worked. It became evident that the conversion training had not adequately informed drivers about the differences between the two braking systems, particularly in low-adhesion conditions, and how the brake effort is shared between the motor car and trailer.

4.5.3. A key difference was the Matangi's preference for using dynamic brakes. This reduced the number of braked wheels to just those wheels on the motor car and consequently it required a higher level of adhesion to deliver that brake force. The effect was that the Matangi would experience wheel slide more often than the Ganz-Mavag in low-adhesion conditions. (See Appendix 3 for more details.)

4.5.4. Another key difference between these two train brake systems was how brake effort was shared between the motor car and trailer. The Matangi computer-controlled brake system applied all brake effort from the motor car before using the trailer car brakes. The Ganz-Mavag stepped the brake effort sequentially in thirds. The first step would apply one-third brake force from the motor car, the next step would add one-third to the trailer, the next would increase the motor car to two-thirds and so on until full service brake had been reached on each car.

4.5.5. In a four-year period, drivers encountered various braking problems with the newly commissioned trains, including dynamic brakes tripping out and their being unable to stop the trains at target points. The problems sometimes resulted in platform overruns, which were subsequently reported to the regulator and the operator but little progress was made in resolving them. This led to drivers losing confidence in the braking system and to experiment with alternative braking techniques or work-around actions.

4.5.6. The operator did not have a best practice of braking in an emergency, so had left it to the drivers' discretion. A benefit of the brake test programme was drivers actually experiencing wheel-slide protection activity while braking on a safe and controlled low-adhesion test track. The operator was subsequently able to define a best-practice braking technique for low-adhesion conditions and retrain its drivers accordingly.

4.6. Subsequent events and preventive measures

4.6.1. On 10 June 2015 at 1039, a third Matangi train[13] had a braking problem at Melling in low-adhesion conditions. The Commission made enquiries into the incident and reviewed the train

[13] Matangi train FP/FT 4218

data logger record. The train had been upgraded with the new brake control software and the driver was aware of the new, best-practice, low-adhesion braking technique.

4.6.2. The train started to slide near the 'on-tracking boards' at the start of the straight into Melling Station, but the driver recognised the wheel-slide protection activity and applied emergency brakes. The train was reported to have come to a stop from 35 km/h in 205 m, which represents a deceleration rate of approximately 0.23 m/s^2. The point where it stopped was before the platform, so the driver then crept the train forward to the desired target stop point, where it was stopped normally.

4.6.3. GWRC arranged for the wheel-slide activity to be presented to the driver's screen of the train management system. This will help drivers to recognise when low-adhesion conditions exist and to implement their defensive driving techniques.

4.6.4. GWRC took the initiative to organise a 'Low-adhesion working group' in the Wellington area. The group has members from all aspects of the rail industry, including the train operator, network manager and infrastructure owner. The working group's purpose is to share information about low-adhesion conditions and collaboratively take action to reduce its effect on operations in the Wellington rail network.

4.6.5. In October 2016 GWRC started the purchasing process for a Matangi train simulator to assist with future driver training. Depending on the fidelity of the simulator controls, it could provide a means to better prepare drivers for handling low-adhesion conditions.

Findings

5. The Matangi braking and wheel-slide protection systems were not performing as well as they could have because they had not been tested against an appropriate standard and tuned for optimum braking in low-adhesion conditions before the trains were commissioned to service.
6. It could not be established whether either collision would have been prevented had the brake and wheel-slide protection systems been operating to their optimum in low-adhesion conditions.
7. The National Rail System Standards do not adequately address the braking performance in low-adhesion conditions of modern metropolitan passenger trains that are fitted with computer-controlled brake and wheel-slide protection systems.
8. The training that drivers received for transitioning from the Ganz Mavag to the Matangi train type did not provide them with sufficient information in respect of the design and correct operation of the train brake and wheel-slide protection systems.

5. Findings

5.1. It is very likely that for both collisions with the stop block at Melling Station, an extended period of dry weather combined with the formation of dew on the rail resulted in a condition of low rail adhesion along the approach to the station.

5.2. It was not possible to determine whether the driver of the Melling 2 train was impaired by cannabis. However, the fact that he had cannabis in his system is a serious safety issue.

5.3. Both trains were travelling at a normal speed of approach to Melling Station and both drivers applied a normal braking technique during the approach.

5.4. The operating risk and potential consequences of a train overrunning the platform at Melling Station and colliding with the stop block had not been adequately considered. No special speed restriction for the approach had been set; the stop block was an older and less effective design than its modern equivalent; and the pole carrying the overhead traction power line was placed directly behind the stop block where it was prone to damage.

5.5. The Matangi braking and wheel-slide protection systems were not performing as well as they could have because they had not been tested against an appropriate standard and tuned for optimum braking in low-adhesion conditions before the trains were commissioned to service.

5.6. It could not be established whether either collision would have been prevented had the brake and wheel-slide protection systems been operating to their optimum in low-adhesion conditions.

5.7. The National Rail System Standards do not adequately address the braking performance in low-adhesion conditions of modern metropolitan passenger trains that are fitted with computer-controlled brake and wheel-slide protection systems.

5.8. The training that drivers received for transitioning from the Ganz Mavag to the Matangi train type did not provide them with sufficient information in respect of the design and correct operation of the train brake and wheel-slide protection systems.

6. Safety actions

6.1. General

6.1.1. The Commission classifies safety actions by two types:

(a) safety actions taken by the regulator or an operator to address safety issues identified by the Commission during an inquiry that would otherwise result in the Commission issuing a recommendation

(b) safety actions taken by the regulator or an operator to address other safety issues that would not normally result in the Commission issuing a recommendation.

6.2. Safety actions addressing safety issues identified during an inquiry

6.2.1. GWRC conducted full train brake tests in sustained low-adhesion conditions then followed up with corrective actions. This resulted in the upgrade of the computer-controlled brake system to ensure that trains would stop in the shortest possible distance in low-adhesion conditions. The software upgrades were rolled out across the fleet during a long weekend in early 2015. This included an indicator to drivers when wheel-slide protection activity was taking place. Further upgrades to the wheel-slide protection systems were completed mid-2016.

6.2.2. KiwiRail retrained the Wellington metro train drivers to better inform them about how the Matangi computer-controlled brakes worked and provided a best-practice braking technique in low-adhesion conditions. All drivers went through a retraining module before the new software was rolled out.

6.2.3. KiwiRail changed the network control operating procedures to ensure that whenever the overhead power to a rail line tripped out the controllers would not reset the power before a thorough and reasonable check to ensure that any trains in the area would not be put at undue risk of electric shock.

6.2.4. GWRC set up and organised a cross-organisation 'Low adhesion working group' for the Wellington area, which representatives from the owner, train maintenance, train operator, networks owner and train control attend. The group meets regularly to focus jointly on mitigating the risks of operating trains in low-adhesion conditions around the Wellington network and to share information that is of use to the group.

6.2.5. GWRC has approved the procurement of a driver simulator for the Matangi to commence in October 2016.

6.3. Safety actions addressing other safety issues

6.3.1. None identified

7. Recommendations

7.1. General

7.1.1. The Commission may issue, or give notice of, recommendations to any person or organisation that it considers the most appropriate to address the identified safety issues, depending on whether these safety issues are applicable to a single operator only or to the wider transport sector. In this case, recommendations have been issued to KiwiRail and the NZ Transport Agency. Notice of the recommendations to the NZ Transport Agency was also given to CAF New Zealand Limited, Auckland Transport and Transdev Auckland.

7.1.2. In the interests of transport safety, it is important that these recommendations are implemented without delay to help prevent similar accidents or incidents occurring in the future.

7.2. Recommendations to KiwiRail

Speed restrictions for terminal stations

7.2.1. Two trains have collided with the stop block at Melling Station in the space of just over one year. The normal line speed for the section of track between the preceding station and Melling is 70 km/h. The Melling Station platform only becomes clearly visible to a train driver once their train has rounded the last bend, about 400 m from the stop block. If trains were restricted to a lower speed before they rounded the last bend, the risk of a platform overrun and resulting collision with the stop block would be reduced.

7.2.2. On 30 June 2014 the Commission recommended that KiwiRail apply a suitable permanent speed restriction to the last section of the Melling Line to reduce the approach speed to Melling Station. (018/14)

7.2.3. On 8 July 2014 the General Manager – Rail Passenger Group advised that KiwiRail had reduced the 'line speed' on the Melling Line from 70 km/h to 50 km/h and imposed a speed restriction of 25 km/h for the approach to Melling Station.

7.2.4. On 26 March 2015 the Commission approved the closure of the recommendation on the basis that the actions taken by KiwiRail had addressed the safety issue.

7.2.5. On 30 June 2014 the Commission recommended that KiwiRail assess all other terminating stations on the controlled network throughout New Zealand and similarly apply permanent speed restrictions as necessary to the approaches at those stations. (019/14)

7.2.6. On 8 July 2014 the General Manager – Rail Passenger Group advised that KiwiRail had:

> Completed a risk assessment for all lines in the metro Wellington region that have no over-run (end of line) with stop blocks to establish that the controls in place are appropriate for managing approach speeds and distances to the stop blocks in the event that there is a similar [occurrence] caused by lack of braking action, and that any resultant impact damage would be adequately contained.
> As a result of the risk assessment, "a 25 km/h speed restriction has been placed on the Johnsonville Line, similar to that which has been introduced for the Melling Line".

7.2.7. On 23 September 2015 the Commission approved the closure of the recommendation on the basis that the actions taken by KiwiRail had addressed the safety issue.

Stop block

7.2.8. The stop block installed at Melling was a solid concrete block with a limited ability to absorb impact forces. It was physically shifted in the first collision, and even further in the second. The second impact also split the concrete block near ground level and allowed it to rotate backward under the train. The train rode up and over the stop block as a consequence, sustaining substantial damage.

7.2.9. Modern shock-absorbing stop blocks used on other terminating train stations on the controlled network reduce the consequences in terms of injury to persons and damage to trains if overruns should occur that lead to trains striking the stop blocks.

7.2.10. On 30 June 2014 the Commission recommended that KiwiRail replace the type of stop block that was in use at Melling with a new shock-absorbing type design that would be matched to the likely impact forces from a Matangi train. (020/14)

7.2.11. On 21 July 2014 the General Manager – Rail Passenger Group replied:

> KiwiRail advises its engineering team is currently in the design phase for the replacement stop block. It is most likely the replacement will be of the “friction retarder” type as used at Britomart Transport Centre, Manukau Station and Onehunga Station. Key design inputs are the train loading, design impact speed and available retarding track length (which could impact on the usable platform length). A similar analysis is being undertaken on the Johnsonville Line buffer stop.

7.2.12. On 23 June 2016 the Commission approved the closure of the recommendation on the basis that the actions taken by KiwiRail had addressed the safety issue.

The overhead traction terminal pole

7.2.13. The stop block at Melling was mounted directly in front of the terminal (last) pole supporting the high-voltage overhead contact wire for the electric trains. At the collision in 2013 the support structure was damaged, and in the 2014 event the pole was snapped off at ground level, causing the overhead contact wire to droop onto the body of the train. The fallen high-voltage line created a risk to the train occupants and delayed the evacuation of the train after it came to rest.

7.2.14. Placing the power pole directly in line with the stop block was a safety issue that increased the potential consequences of a train overrunning the station platform and striking the stop block.

7.2.15. On 30 June 2014 the Commission recommended that KiwiRail relocate the terminal pole for the overhead line at Melling Station to be clear of the potential train overrun path. (021/14)

7.2.16. On 21 July 2014 the General Manager – Rail Passenger Group replied:

> KiwiRail advised that as part of the “friction retarder” type buffer solution being implemented in response to recommendation 020/14, a design for an offset pull-off pole is being prepared. This will remove the terminal pole from track centre and relocate to a location where it would not be foul of a railed train. It is expected that his design will also be considered for the terminal pole at Johnsonville Station.

7.2.17. On 16 December 2015 the Commission approved the closure of the recommendation on the basis that the actions taken by KiwiRail had addressed the safety issue.

7.3. Recommendations to NZ Transport Agency

Rail standards for new trains

7.3.1. The National Rail System Standard 6 – Engineering and Interoperability (NRSS/6) is the only standard within the National Rail System set that defines braking performance. However, it does not address the performance in low-adhesion conditions of modern metropolitan passenger trains that are fitted with computer-controlled brake and wheel-slide protection systems. The current NRSS/6 does not require any more from a braking system than that a train is able to stop within a specified distance in normal climatic conditions and with a maximum adhesion of 12%.

7.3.2. The regulator for the country of operation or the owner may define what adhesion conditions might be encountered on a rail network and what level of braking performance is expected from a new train and what standards the train is to be tested to for compliance. This is also the stage in commissioning a new train when the interactions between all of the brake systems are adjusted to achieve the optimum overall brake performance. The Rail Safety and Standards Board in the UK has produced a guidance note (GM/GN2695) to achieve this purpose in the UK but nothing similar exists for New Zealand.

7.3.3. The Matangi train brake systems were tested for compliance and proper operation, but they were not tested and adjusted for optimum brake performance in low-adhesion conditions. The Commission considers that the occurrences in Wellington may be repeated unless the NRSS is revised.

7.3.4. As a minimum the Commission considers that the NRSS should call upon appropriate international standards to formalise new train type testing and ensure that train braking systems are tested in low-adhesion conditions and optimised for the trains.

7.3.5. On 26 March 2015 the Commission recommended that the Chief Executive of the NZ Transport Agency require a full review of the NRSS, and in particular NRSS/6, to ensure that low-adhesion braking requirements are defined in the standards and made applicable for all trains intended to operate on the National Rail System. (005/15)

7.3.6. On 11 May 2015 the Chief Executive of the NZ Transport Agency responded:

> While the Transport Agency cannot 'require' a full review of the National Rail System Standards (NRSS), it is the Transport Agency's intention to work with the NRSS executive to ensure relevant aspects of low adhesion braking capability are reflected in the appropriate standard.

Auckland trains

7.3.7. The Commission is aware that new passenger trains have recently been introduced in Auckland. The Commission is not aware of any safety issues with the new trains, but expects that they would have been tested to comply with the same National Rail System standards as the Matangi trains in Wellington. Therefore, they may be exposed to the same lack of optimised brake performance risks in low-adhesion conditions.

7.3.8. On 26 March 2015 the Commission recommended that the Chief Executive of the New Zealand Transport Agency review the process followed for the commissioning of the Auckland trains, and if they have not been optimised for low adhesion conditions or adhesion management systems introduced to reduce the risk of incidents across the network, he address those safety issues in line with the safety actions planned for the Matangi train operation (006/15)

7.3.9. On 11 May 2015 the Chief Executive of the NZ Transport Agency responded:

> The Transport Agency has commenced discussions with Auckland Transport and CAF regarding this recommendation.

7.3.10. On 9 April 2015 the Commission gave notice of preliminary safety recommendations 005/15 and 006/15 under section 9 of the Transport Accident Investigation Commission Act 1990 to the following parties:

- the Depot General Manager, CAF New Zealand Limited as the manufacturer and maintainer of the new Auckland trains
- the Chief Executive Officer of Auckland Transport as the owner of the new Auckland trains
- the Managing Director of Transdev Auckland as the operator of the new Auckland trains.

8. Key lessons

8.1 Slippery track conditions are a foreseeable risk and train braking systems must be designed, tested and optimised to provide adequate braking performance under those conditions.

8.2 Train drivers must be adequately trained to be fully conversant with the characteristics of their train braking systems, and to drive their trains within the trains' capabilities.

8.3 When a new train type is being commissioned and first entered into service, train operators should seek feedback from the drivers on train performance in order to identify and remedy promptly any potential performance issues.

9. Citations

Ashton, H. C. (2001). Pharmacology and effects of cannabis: a brief review. *British Journal of Psychiatry*, 178: 101-106.

ATSB. (2013). *Collision of passenger train T842 with station platform, report RO-2013-005.* Canberra: Australian Transport Safety Bureau.

Crean et al, R. D. (2011). An evidence based review of acute and long-term effects of cannabis on executive cognitive functions. *J Addict Med*, 5(1): 1-8. doi:10.1097/ADM:0b013e31820c23fa.

Huestis, M. A. (2007). Human cannabinoid pharmacokinetics. *Chem Biodivers*, 4(8): 1770-1804, doi:10.1002/cbdv.200790152.

OCITS. (2009). *Platform overruns, Siemans Nexas EMU, Connex/Metro Trains Melbourne.* Melbourne: Office of the Chief Investigator Transport Safety.

Olofsson, U., & Lewis, R. (2006). Tribology of the wheel-rail contact. In D. o. Railway Group KTH. Stockholm, Sweden: Taylor and Francis Group, LLC.

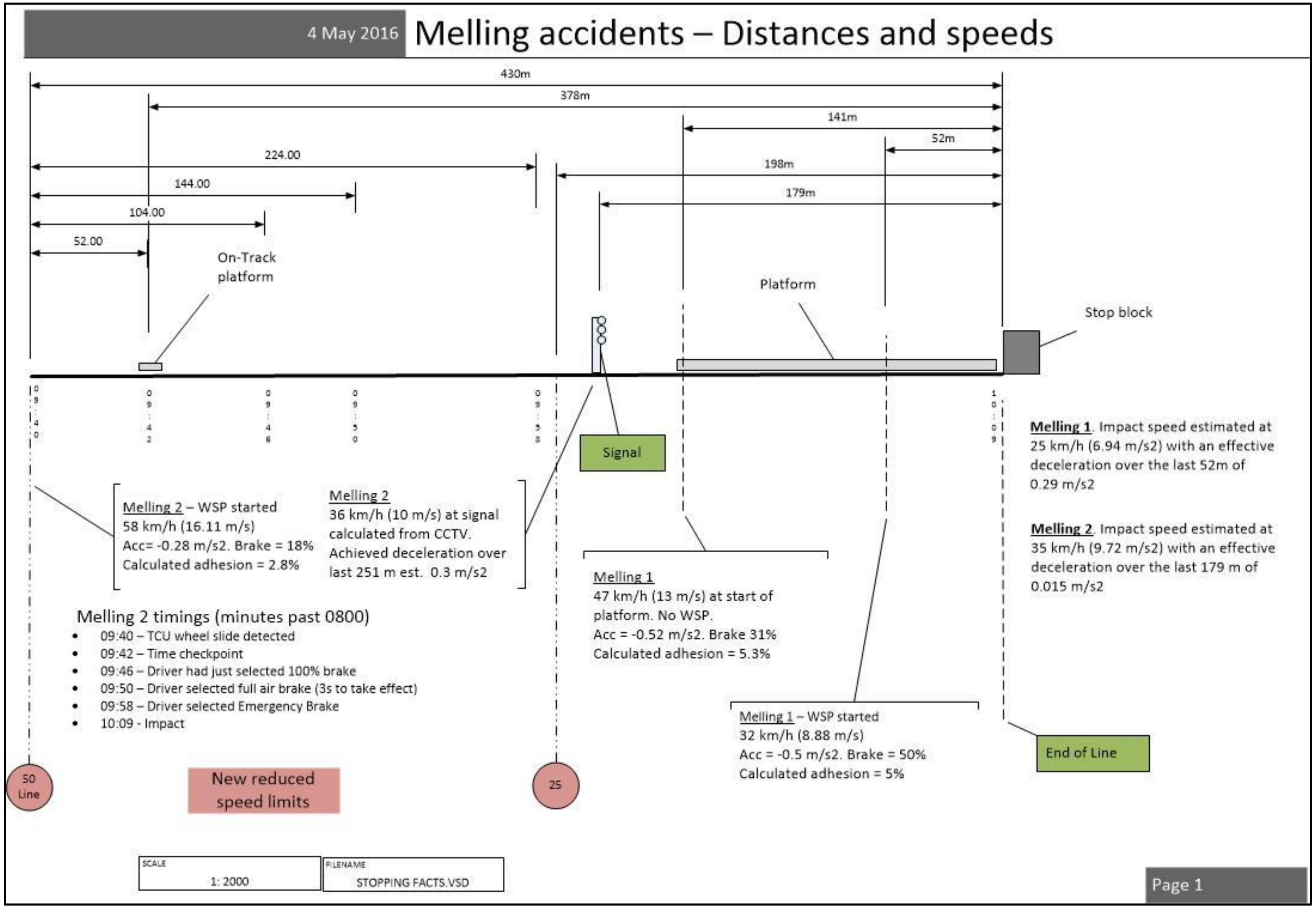
RAIB. (2005). *Autumn adhesion investigation part 3: Review of adhesion-related incidents, Autumn 2005.* Derby: Rail Accident Investigation Branch, Department for Transport, UK.

RSSB. (2004). *Review of Low Adhesion Research.* Rail Safety Standards Board.

TCRP. (1997, May). Improved methods for increasing wheel/rail adhesion in the presence of natural contaminatiion. *Research Results Digest, Number 17*.

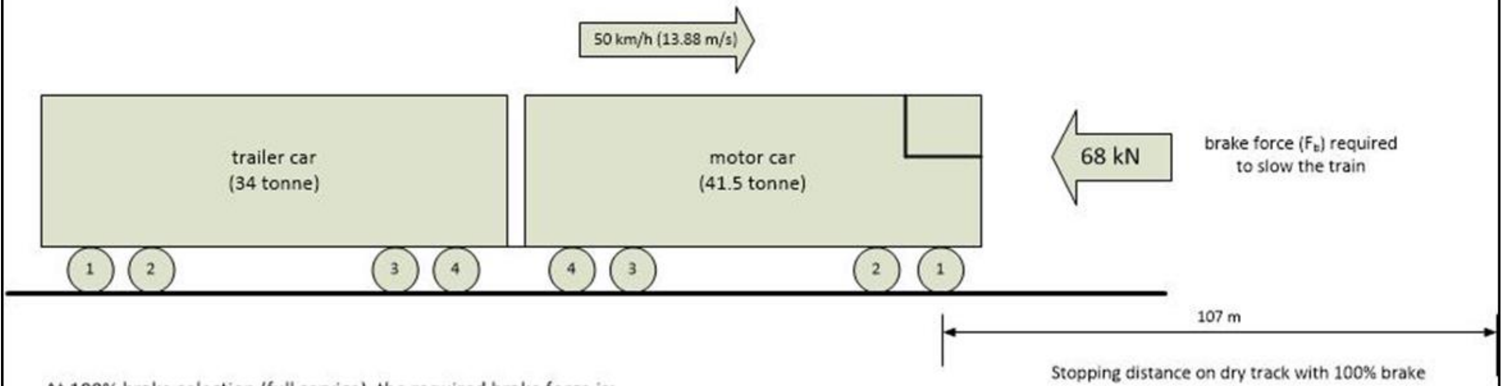
Zhu, Y. (2013). *Adhesion in the wheel-rail contact.* Stockholm: Doctoral Thesis, Department of Machine Design, Royal Institute of Technology.

Appendix 1: Distances and speeds



Appendix 2: Brake calculations

brake deceleration rates
full service = 0.9 m/s^2
emergency = 1.2 m/s^2



At 100% brake selection (full service), the required brake force is:
$F_b = M \times a$ ......1 (Newton's second law) where F_b = the brake force, M = total mass and, a= deceleration

$F_b = (34+41.5 \text{ tonne}) \times 0.9\ m/s^2 = \underline{68\ kN}$ (kilo Newtons)

If the adhesion level had reduced to 5% and the brake system worked perfectly, this stopping distance would almost double to 197 m

The distance required to stop at 100% brake effort (assuming that the wheels do not slide) is:
$s = (V^2 - U^2)/2a$ ......2 where s= distance, v= initial speed, u= final speed, a= deceleration

$S = (13.88^2 - 0^2)/2 \times 0.9 = \underline{107}$ metres

If the adhesion level is very low at 5% and assuming a perfect wheel slide protection system that allows maximum brake effort with controlled creep, the maximum brake deceleration would be:
$a = (\mu/100) \times g$ ....3 where a = deceleration rate, μ= the adhesion level expressed as a percentage, and g= the acceleration force of gravity.

$a = (5/100) \times 9.81\ m/s^2 = 0.49\ m/s^2$

From 2, $s = (13.88^2 - 0^2) / 2 \times 0.49 = \underline{197}$ metres

For more information on adhesion and these formulae, see:

Rail Safety and Standards Board Limited, London, England.
guidance note GM/GN2643

Appendix 3: Required coefficient of friction

Example of Matangi deceleration using the information and diagram in Appendix 2

Full train braking

If the brake force is to be applied evenly across all wheels.

The Normal force for the train is the force that acts vertically downwards on the train mass as a result of gravity and is represented as: Fn = ma

Fn = (34 t + 41.5 t) x 9.81 m/s^2 = 760.6 kN

Therefore the normal force per wheel: = Fn/(8 x 2) = 46.3 kN

Assume that all wheels are braked evenly and total required decelerating force is 68 kN

Therefore the required brake force (Fa) per braked wheel is 68 kN/(8 x2) = 4.25 kN

As the friction coefficient $\mu = \frac{Fa}{Fn}$, the minimum required friction coefficient needed to apply this braking force without causing wheel slide is:

4.25/46.3 = 0.091 = 9%

Motor car braking only

If all braking must be provided by the motor car, the required deceleration force to slow the train remains the same but it must be applied through fewer wheels, so the minimum required friction coefficient will increase.

The motor car normal force: = 41.5 t x 9.81 m/s^2 = 407 kN

Therefore the normal force per wheel: = 407 kN/(4 x 2) = 50.9 kN

The required brake force to stop the train is the same but it is shared across fewer wheels. The brake force per wheel: = 68 kN/(4 x 2) = 8.5 kN

The minimum required friction coefficient is now:

8.5/50.9 = 0.16 = 16%

Conclusion

When the computer-controlled brake system applies only dynamic brakes to slow the train, a greater level of adhesion is required to achieve the selected deceleration rate than would be required if the brake effort were spread across the motor car and trailer car.

If this minimum required adhesion is not available, the motor car wheels will start to slide.

Appendix 4: Research on rail adhesion

A.1 The rolling contact surface area between the wheel tread and the top of the rail head plays a critical part in the operation of all railway systems. This contact area is called the 'contact patch'. If the friction of this contact patch is too low, the wheels will lose adhesion and slip when the train accelerates or slide when it brakes.

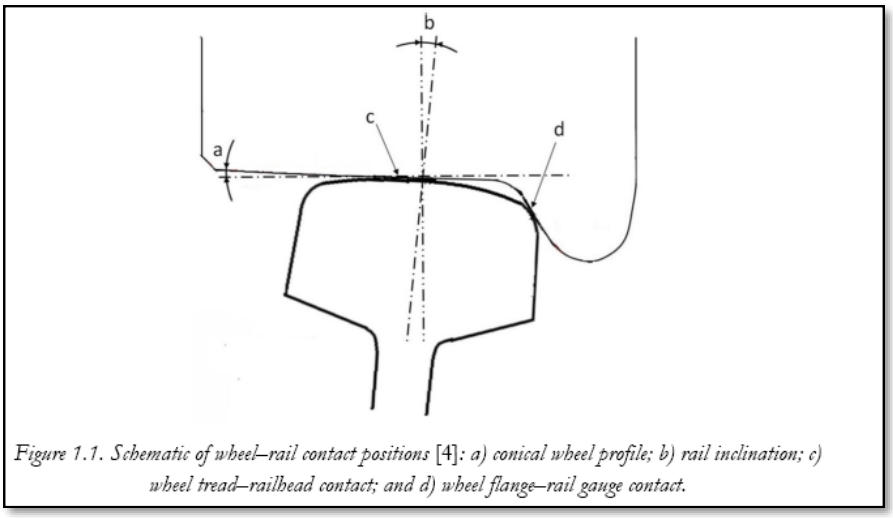


Figure 8
Rail-to-wheel contact
(Zhu, 2013)

A.2 The rolling contact patch is oval shaped and typically about 100 square millimetres in area. For a driven or braked wheel it consists of two regions called the 'stick' and the 'slide' regions (Olofsson & Lewis, 2006). These regions vary depending on the applied traction or braking force. When a train is coasting, with no power or braking, the whole contact patch area is 'stick'. When brake force is applied the surface speed of the wheel moves slightly slower than the speed at which the train is moving over the rail. This rolling friction causes the stick region of the contact patch to reduce with a consequential increase in the slide region.

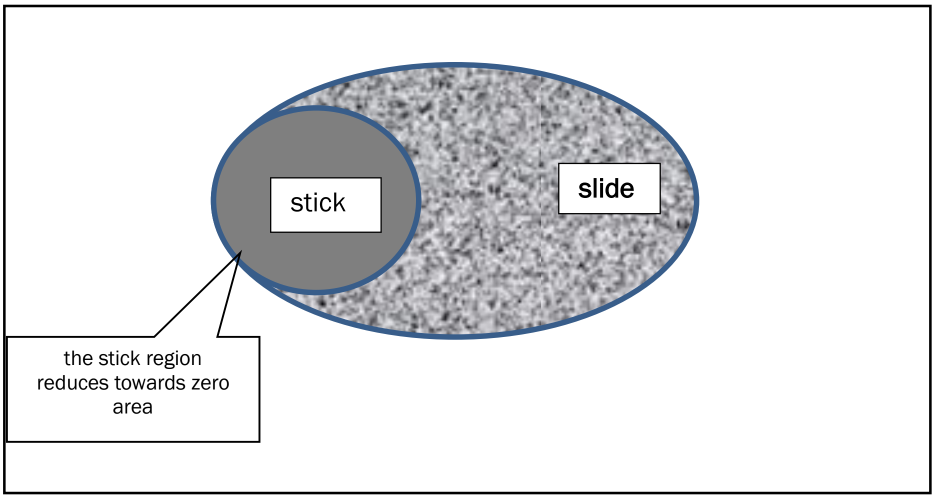


Figure 9
Contact patch

A.3 The forces relevant to slowing a train are demonstrated in Figure 10. The train velocity is shown as the vector (v) and the rotational velocity of the wheel tread as ωr (pronounced omega-r). The difference between these two velocities is called 'creep' and it is usually expressed as a percentage of the rail vehicle velocity.

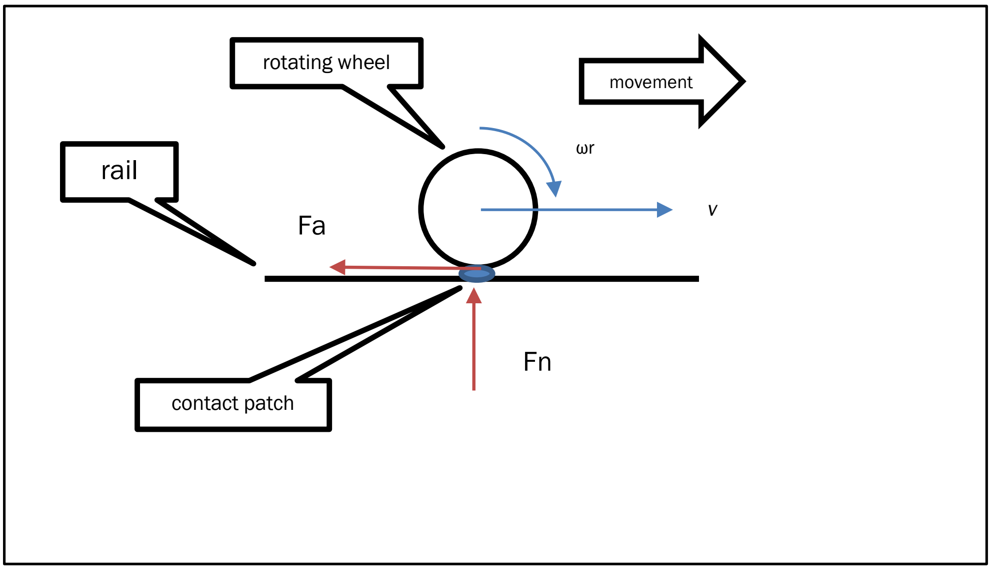


Figure 10
Wheel-rail interface

A.4 Adhesion force (Fa) is the transmitted tangential force in the longitudinal direction between the railway wheel and the rail. It can be used to describe both the accelerating and the braking force applied to a rail vehicle. Adhesion is dependent upon the coefficient of friction between the two surfaces in contact and related by the formula:

$$\mu = \frac{Fa}{Fn}$$

[Where μ = Coefficient of friction (often expressed as a percentage), Fa = maximum adhesion force at the point of slide, and Fn = the Normal[14] reaction force due to the weight of the vehicle.]

A.5 The friction ratio will change as the brake force increases due to the dynamics of the 'stick' and 'slide' regions of the contact patch The friction ratio will increase sharply to a peak at around 2% creep, then decrease at a slower rate as the applied brake force and creep continue to increase (see Figure 11). The peak of this curve represents the coefficient of friction at the point of slide and the maximum available adhesion. The slope beyond the peak is the desired control range of wheel creep that wheel slide protection systems use. If the wheel creep is allowed to increase too far by applying more brake force, the 'stick' region of the contact patch will reach a point where it is unable to absorb any further increase in brake force and the wheel will lock up and slide along the rail.

[14] Normal is a vector that is acting in a direction perpendicular to the reference surface.

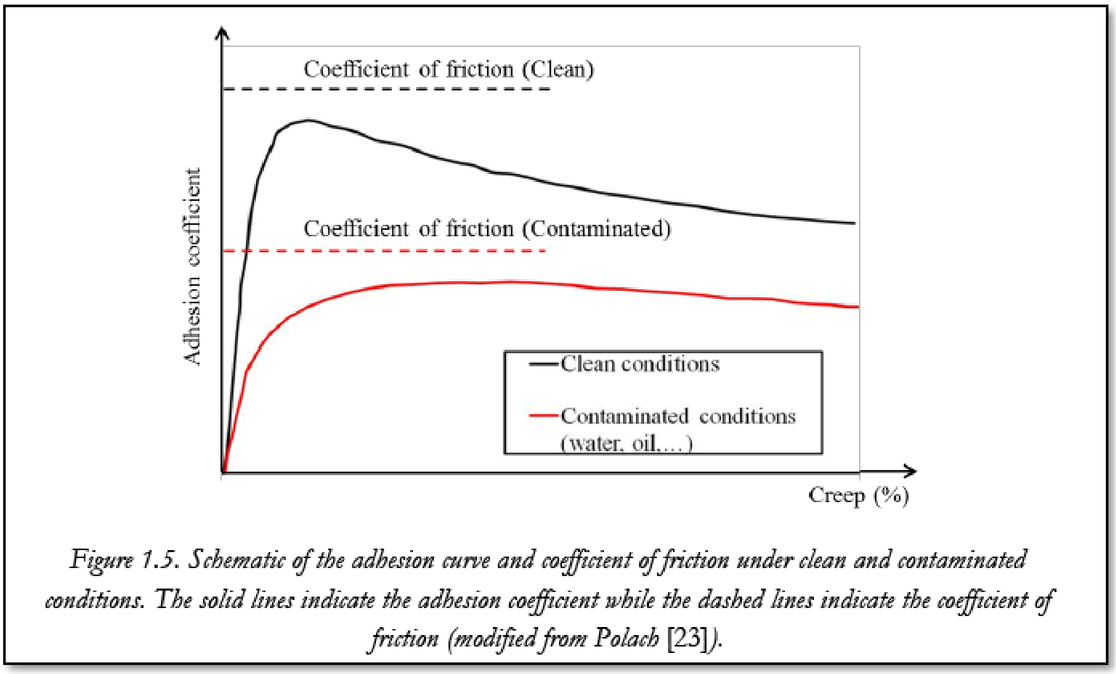


Figure 11
Adhesion related to slide
(Referred to as creep in this graph from Zhu, 2013)

Low adhesion

A.6 The coefficient of friction between a rail vehicle's wheel tread and a dry rail is normally between 12% and 40%. Low adhesion is defined as when the coefficient of friction is at 10% or less. Very low adhesion is a subset of low adhesion when the adhesion level is less than 5%. When the interface is contaminated by a third body the coefficient of friction may change for the better or worse. Often rail operators inject sand into the contact patch area to increase adhesion or natural contaminants may collect on the rail head that reduce adhesion.

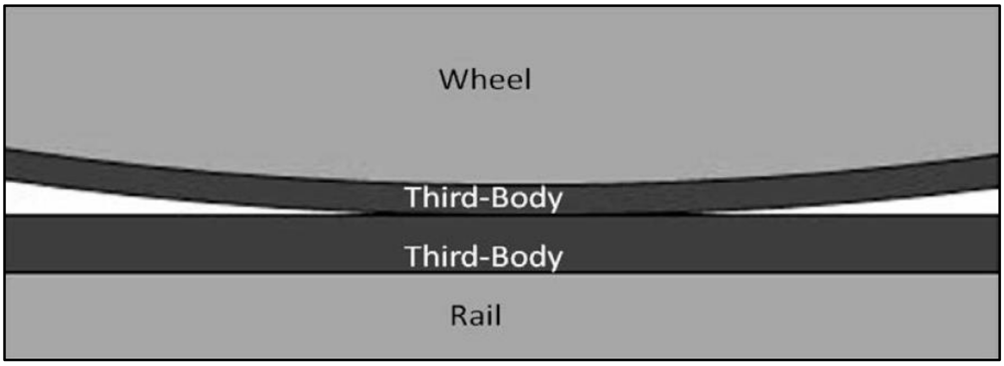


Figure 12
Contamination of the wheel-rail interface

A.7 A North American research project conducted by the Transit Cooperative Research Program found that low-adhesion conditions occurred in light drizzle, in the early mornings and on icy, frosty rails. The research survey of 24 light rail and commuter rail transit agencies in North America was intended to gain a better understanding of the wheel-to-rail adhesion in the presence of natural contaminants. The results are summarised in its digest (TCRP, 1997).

A.8 A chemical analysis of rail head contaminants conducted by British Rail and the Association of American Railroads showed that the rail head is normally covered with a thin film of active oils, grease and solid debris. It found that the oils contained large organic molecules, acid ester, ketone, amines and sulphur-containing compounds. The solid debris was oxides of iron and other locally found components such as dirt and brake dust. These combined to form a surface film that could not be removed chemically or by scrubbing. With the addition of small amounts of water the film formed a slurry or paste that reduced adhesion. The research project concluded that "moisture, even in small amounts, on the surface of the rail is the single most important contaminant responsible for low adhesion".

A.9 Beagley et al (cited in Zhu, 2013) published several papers in the Wear journal in 1975 that described research into adhesion between the wheel-rail contact and the effects of contaminants of water, oil and wear debris. Beagley found that a small amount of water mixed with substantial quantities of debris could form a paste that significantly reduced adhesion. The paste was squeezed aside if the water was sufficient. Zhu's research also confirmed findings by several other researchers cited in his thesis, that relative humidity (RH) influenced the friction coefficient up to 55-65% RH but made no further change above that level of humidity. This was associated with water molecules forming a boundary lubrication film around the natural contaminants on the rail head.

A.10 The Rail Safety and Standards Board in the UK carried out a review of available research into low adhesion in 2004. It found that low adhesion could not be attributed to a single cause, but the most widespread effect noted was that of dew or newly falling rain on rails covered in tiny particles of oil or debris. On a visibly rusty rail the film formed by the rust debris and water molecules can support the wheel completely, and extremely low adhesion can result. With more consistent rainfall, the viscosity of the film is so low that it is readily squeezed aside, returning the adhesion to a higher level (RSSB, 2004).

Appendix 5: Research on cannabis impairment

A.1 There are several paths for a person to ingest cannabis, with variable concentrations of dosage that, when combined with the variations in the human body shape, size and internal efficiency, result in a range of reactions.

A.2 Once absorbed into the body, the THC[15] and other cannabinoids are rapidly distributed to all other tissues at rates dependent on the blood flow. Because they are extremely lipid soluble, cannabinoids accumulate in the fatty tissues, reaching peak concentrations in four or five days. After ingestion cannabinoids are metabolised in the liver then slowly released back into the body compartments, including the brain. More than 20 metabolites are known, of which some are psychoactive and one (11-hydroxy-THC) may be more potent than THC. Metabolites are partly excreted in the urine but mainly into the gut, where they are reabsorbed, further prolonging their actions. Consequently, there is a very poor relationship between the plasma or urine concentration and the degree of cannabinoid-induced intoxication (Ashton, 2001).

A.3 The detection of cannabinoids in urine is indicative of prior cannabis exposure, but the long excretion half-life of cannabis acid in the body, especially in chronic users, makes it difficult to predict the timing of past drug use. A positive urine test does not provide information on the route of administration, the amount of drug exposure, when drug exposure occurred, or the degree of impairment (Huestis, 2007).

A.4 A 2011 literature review of research into the effects of cannabis use on the executive cognitive functions found that it impaired information processing, which is a building block for attention and concentration. Other executive functions affected were planning, decision-making, risk taking, inhibition, impulsivity and working memory. The review found that recently abstinent users (7 hours to 20 days) may or may not continue to experience impairment of attention, concentration, inhibition and impulsivity during the interval associated with the elimination of THC and its metabolites from the brain. Decision-making and risk-taking capabilities had not been thoroughly studied at the time but one study cited in the review suggested that these abilities were also impaired for an extended period after exposure (Crean et al, 2011).

[15] THC = delta-9-Tetrahydrocannabinol.

Recent railway occurrence reports published by the Transport Accident Investigation Commission (most recent at top of list)

RO-2015-101	Pedestrian fatality, Morningside Drive pedestrian level crossing, West Auckland, 29 January 2015
RO-2014-101	Collision between heavy road vehicle and the Northern Explorer passenger train, Te Onetea Road level crossing, Rangiriri, 27 February 2014
RO-2012-103	Derailment of freight Train 229, Rangitawa-Maewa, North Island Main Trunk, 3 May 2012
RO-2012-105	Unsafe recovery from wrong-route, at Wiri Junction, 31 August 2012
RO-2013-107	Express freight MP16 derailment, Mercer, North Island Main Trunk, 3 September 2013
RO-2012-104	Overran limit of track warrant, Parikawa, Main North line, 1 August 2012
RO-2013-104	Derailment of metro passenger Train 8219 , Wellington, 20 May 2013
Urgent Recommendations RO-2015-101	Pedestrian fatality, Morningside Drive level crossing, West Auckland, 29 January 2015
RO-2013-105	*Capital Connection* passenger train, departed Waikanae Station with mobility hoist deployed 10 June 2013
RO-2014-102	High-speed roll-over, empty passenger Train 5153, Westfield, South Auckland, 2 March 2014
RO-2013-106	Track occupation irregularity, leading to near head-on collision, Otira-Arthur's Pass, 10 June 2013
RO-2012-102	Train control power failure, 26 April 2012
Interim Report RO-2014-103	Metropolitan passenger train, collision with stop block, Melling Station, Wellington, 27 May 2014
RO-2013-108	Near collision between 2 metro passenger trains, Wellington, 9 September 2013
11-106	Hi-rail vehicle nearly struck by passenger train, Crown Road level crossing near Paerata, North Island Main Trunk, 28 November 2011
11-102	Track occupation irregularity, leading to near head-on collision, Staircase-Craigieburn, 13 April 2011

Price $18.00

ISSN 1178-4164 (Print)
ISSN 1179-9102 (Online)