Final report RO-2014-105: Near collision between train and hi-rail excavator, Wairarapa Line near Featherston, 11 August 2014

The Transport Accident Investigation Commission is an independent Crown entity established to determine the circumstances and causes of accidents and incidents with a view to avoiding similar occurrences in the future. Accordingly it is inappropriate that reports should be used to assign fault or blame or determine liability, since neither the investigation nor the reporting process has been undertaken for that purpose.

The Commission may make recommendations to improve transport safety. The cost of implementing any recommendation must always be balanced against its benefits. Such analysis is a matter for the regulator and the industry.

Final Report

Rail inquiry RO-2014-105
Near collision between train and hi-rail excavator,

Wairarapa Line near Featherston

11 August 2014

Approved for publication: June 2017

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.

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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

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	

Source: mapsof.net

Location of incident

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Abbreviations

Commission	Transport Accident Investigation Commission
KiwiRail	KiwiRail Holdings Limited

Glossary

hi-rail excavator	an excavator equipped with retractable hi-rail wheels such that it can be driven along a railway track
information bulletin	an unnumbered instruction issued by KiwiRail Network Authorities in Wellington, usually the day before it comes into effect. The information bulletin is distributed to all operating staff who may be affected, including train drivers, passenger staff and infrastructure maintenance staff
KiwiRail Network Authorities	KiwiRail Network Authorities prepare and issue information bulletins that include planned track work carried under Track and Time Permits, Compulsory Stop Protection or track warrants. An information bulletin can also include additional passenger train arrangements, special instructions for the day of operation and work trains
line impassable	a term used when planned work requires the closing of a track to normal train movements for a period of time to allow that work to be carried out. Train control may vary the hours of work when the planned work starts or has finished before the stated time
rail protection officer	the generic name given to a person protecting individuals or multiple worksites who is responsible for co-ordinating the movement of trains and hi-rail vehicles into and within a protected work area
safe place	a place where people and equipment cannot be struck by passing rail traffic
track warrant	an authority by train control defining limits and other instructions for the occupation of the mainline

Data summary

Vehicle particulars

Train type and number:	empty passenger Train F16, travelling from Featherston to Masterton, consisting of two diesel-powered locomotives hauling six empty passenger carriages. The train had an overall length of 166 metres and a total weight of 405 tonnes, including the locomotives
Operator:	KiwiRail Holdings Limited

Date and time	11 August 2014 at about 0319[1]
Location	Bridge 49, between Featherston and Dalefield, Wairarapa Line
Injuries	nil
Damage	nil

[1] Times in this report are New Zealand Standard Times (universal co-ordinated time + 12 hours) and are expressed in the 24-hour mode.

1. Executive summary

1.1. At 2230 on Friday 8 August 2014, a worksite was established between Dalefield and Featherston on the Wairarapa Line to enable rail sleepers to be replaced on two rail bridges. Work was scheduled for the whole weekend, with the line to re-open at 0300 on Monday 11 August 2014.

1.2. Protection for the work area was achieved by train control issuing a track warrant to the rail protection officer, the person responsible for the safety and protection of personnel at the worksite. Trains were not scheduled, and not permitted to travel, through the worksite for the period to which the track warrant applied.

1.3. The rail protection officer did not remain at the site for the entire period. He travelled between his home in Wellington and the worksite several times throughout the weekend. He was not on site at 0300 on Monday 11 August when the track warrant was due to be cancelled. Instead he had instructed the leading hand for each of the work groups at the two bridges to phone him and report when their work group had completed the work and was clear of the track.

1.4. The rail protection officer received the all-clear from one of the leading hands, but the other work group had not completed the work. He was unable to make contact with the other leading hand, so he assumed they were clear of the track and cancelled the track warrant with train control.

1.5. Train control then issued a track warrant for an empty passenger train to pass through the area. The driver of the train noticed the flashing light of a hi-rail excavator working on the rail bridge ahead and stopped his train about 180 metres short of the hi-rail excavator and the work group that was occupying the track. There was no collision and nobody was injured.

1.6. The Transport Accident Investigation Commission (Commission) found that a near collision between the train and the hi-rail excavator occurred because the rail protection officer informed train control that the worksite was clear without first checking positively that it was.

1.7. The Commission found that the KiwiRail process for planning and authorising the worksite was not entirely followed and that this contributed to the incident. The planning process did not address how rail activities within and through the protected work area would be controlled during the 52.5-hour work period.

1.8. The Commission also found that it was likely that the rail protection officer was affected by an underlying level of fatigue and sleep inertia when he made the incorrect assumption that the work had been completed and that the track was safe for trains to pass over. KiwiRail was not effectively managing the rail protection officer's day-to-day workload.

1.9. The Commission recommended that KiwiRail review the company's Fitness for Work Policy to ensure that the workloads of personnel undertaking safety-critical work, including staff not on a roster, are managed effectively and that the risk of staff suffering from the effects of fatigue is mitigated.

1.10. Key lessons arising from this inquiry are:

- not following standard railway operating procedures that are designed to provide for safe railway operations is highly likely to result in an accident
- decisions that can affect the safety of railway workers should never be based entirely on assumptions, as in this case when clearance was given for trains to pass through the area when workers were still occupying the track.

2. Conduct of the inquiry

2.1. The incident occurred at a planned work area between Featherston and Dalefield on the Wairarapa Line at about 0319 on Monday 11 August 2014. The NZ Transport Agency notified the Transport Accident Investigation Commission (Commission) at 0730 that morning. The Commission opened an inquiry under section 13(1) b of the Transport Accident Investigation Commission Act 1990 to determine the circumstances and causes of the occurrence and appointed an investigator in charge.

2.2. Commission investigators conducted an interview with the rail protection officer[2] for the planned work area later that morning before travelling to the work area to conduct a site examination.

2.3. The two-person train crew were interviewed separately by the Commission investigators in Masterton the following day.

2.4. On 13 August 2014 the Commission investigators interviewed separately members of KiwiRail Holdings Limited's (KiwiRail's) work group who had been on site at the time of the incident.

2.5. KiwiRail's Central Regional Production and Planning Manager and the driver of the hi-rail excavator[3] working on site under KiwiRail's supervision were interviewed separately on 18 August 2014.

2.6. The Commission obtained the following records and documents for analysis:

- the application for planned work
- KiwiRail's Track Safety Rules
- witness statements
- the downloaded data from the train's event recorder
- the train controller's voice recording
- the train control diagram
- the track warrant[4] issued by the train controller to the rail protection officer for the planned work
- the track warrant issued to the driver of the repositioning passenger train
- the training records for the rail protection officer
- drug and alcohol testing results for KiwiRail staff at the accident site
- the rail protection officer's cell phone records.

2.7. The Commission engaged Associate Professor Leigh Signal of the Sleep/Wake Research Centre at Massey University to review the rail protection officer's workload and the opportunity he had for restorative sleep.

2.8. On 29 March 2017 the Commission approved the draft report for distribution to interested persons for comment.

2.9. The Commission received comments from four interested persons. Any changes made resulting from those submissions have been included in this final report.

2.10. On 28 June 2017 the Commission approved this final report for publication.

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[2] A rail protection officer is a person protecting individuals or multiple worksites who is responsible for co-ordinating the movement of trains and hi-rail vehicles into and within a protected work area.
[3] A hi-rail excavator is an excavator equipped with retractable hi-rail wheels such that it can be driven along a railway track.
[4] A track warrant is an authority by train control defining limits and other instructions for the occupation of the mainline.

3. Factual information

3.1. Background information

3.1.1. KiwiRail owns, maintains and manages the occupancy of, and the movement of trains and hi-rail vehicles over, most of the New Zealand rail network. KiwiRail Network Authorities[5] prepare and issue daily information bulletins[6] that include planned track and bridge maintenance work carried out under the KiwiRail Track Safety Rules.

3.1.2. On Tuesday 29 July 2014, an Application for Planned Work (Form 1, see Appendix 1) was submitted to KiwiRail Network Authorities for approval. The application was to establish a planned work area between the north end station limits at Featherston and the Dalefield Intermediate Board, on the Wairarapa Line, from 2230 on Friday 8 August 2014 to 0300 on Monday 11 August 2014.

3.1.3. The planned work was bridge sleeper replacement work on Bridges 49 and 52. The application requested that the work area be protected by train control issuing a track warrant to a rail protection officer. The application requested that the planned work area be classified as 'line impassable[7]' throughout the work period.

3.1.4. When a work area exceeds one kilometre in length KiwiRail's Track Safety Rule 901, Job Planning, requires that a work area communication plan (Form 2) be submitted with the application, specifying how the rail protection officer intends to communicate with protected personnel and drivers of hi-rail vehicles. Although the application showed that both a work area communication plan and a signals and interlocking diagram were attached to the application, these supporting documents were not submitted.

3.1.5. 'Rail protection officer' is a generic term given to the person responsible for protecting individuals or multiple worksites depending on the level of competency held. That person has overall responsibility for communicating with train control and co-ordinating the movement of trains and hi-rail vehicles through and within the work area. In this case, all scheduled trains were cancelled while the planned work was in progress.

3.1.6. The application was approved by KiwiRail Network Authorities without the complete documentation being submitted. The information bulletins were distributed to all the depots where staff might be affected by the planned work (see Appendix 2, information bulletin dated 8 August 2014, issued at 1458 the previous day). The information bulletin showed that the planned work area was protected under KiwiRail's Operating Rule 401 (d). The rule allowed the train controller to issue a track warrant to the rail protection officer for work on the mainline without other protection.

3.1.7. The information bulletin showed the limits of the protected work area as Featherston and Dalefield, identified the name and contact details of the rail protection officer, and described the sleeper replacement work activity on Bridge 49 and Bridge 52 as multiple activities, Kiwi Rail Track Safety Rule 910. Overgrowth removal work was proposed within the same protected work area, but that work did not get underway because of adverse weather conditions.

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[5] KiwiRail Network Authorities prepare and issue information bulletins that include planned track work carried under track and time permits, compulsory stop protection or track warrants. An information bulletin can also include additional passenger train arrangements, special instructions for the day of operation and work trains.

[6] An information bulletin is an unnumbered instruction issued by KiwiRail Network Authorities in Wellington, usually the day before it comes into effect. The information bulletin is distributed to all operating staff who may be affected, including train drivers, passenger staff and infrastructure maintenance staff.

[7] 'Line impassable' is a term used when planned work requires the closing of a track to normal train movements for a period of time to allow that work to be carried out. Train control may vary the hours of work when the planned work starts or has finished before the stated time.

3.2. The occurrence

3.2.1. On Friday 8 August 2014, the rail protection officer worked from his Wellington office between 0700 and 1400 then drove home. He left home at about 2000 and reached Featherston by about 2030.

3.2.2. The train controller issued Track Warrant 88 to the rail protection officer authorising a track occupation between Featherston and Dalefield until 0300 on Monday 11 August 2014 (see Appendix 3). The mainline had been reported clear at 2153. The radio call signs of seven hi-rail vehicles were listed on the track warrant, which had authority to operate within the protected work area under instruction from the rail protection officer.

3.2.3. The rail protection officer's read back of the track warrant to the train controller was confirmed correct at 2155. The train controller enquired whether the rail protection officer was going home in the morning and handing over the track warrant to someone else. His response was,

> "I would hold the track warrant through to the finish. There will be new groups coming on site at each bridge at six tomorrow morning and finishing at six tomorrow evening when they would be replaced by the crews working tonight, so the work will be continuous. I am more or less holding on to the permit until it is finished on Monday morning."

3.2.4. At 2214 the rail protection officer made a cell phone call to the structures field engineer who was at Bridge 52 to confirm the details of Track Warrant 88. The structures field engineer then held a pre-shift safety briefing with the 12-person work group before the sleeper replacement work started.

3.2.5. The rail protection officer drove from Featherston Station to Bridge 49 (see Figure 1) after he completed his cell phone call with the structures field engineer. The track warrant was shown to the leading hand before he gave a pre-shift safety briefing to all personnel on site.

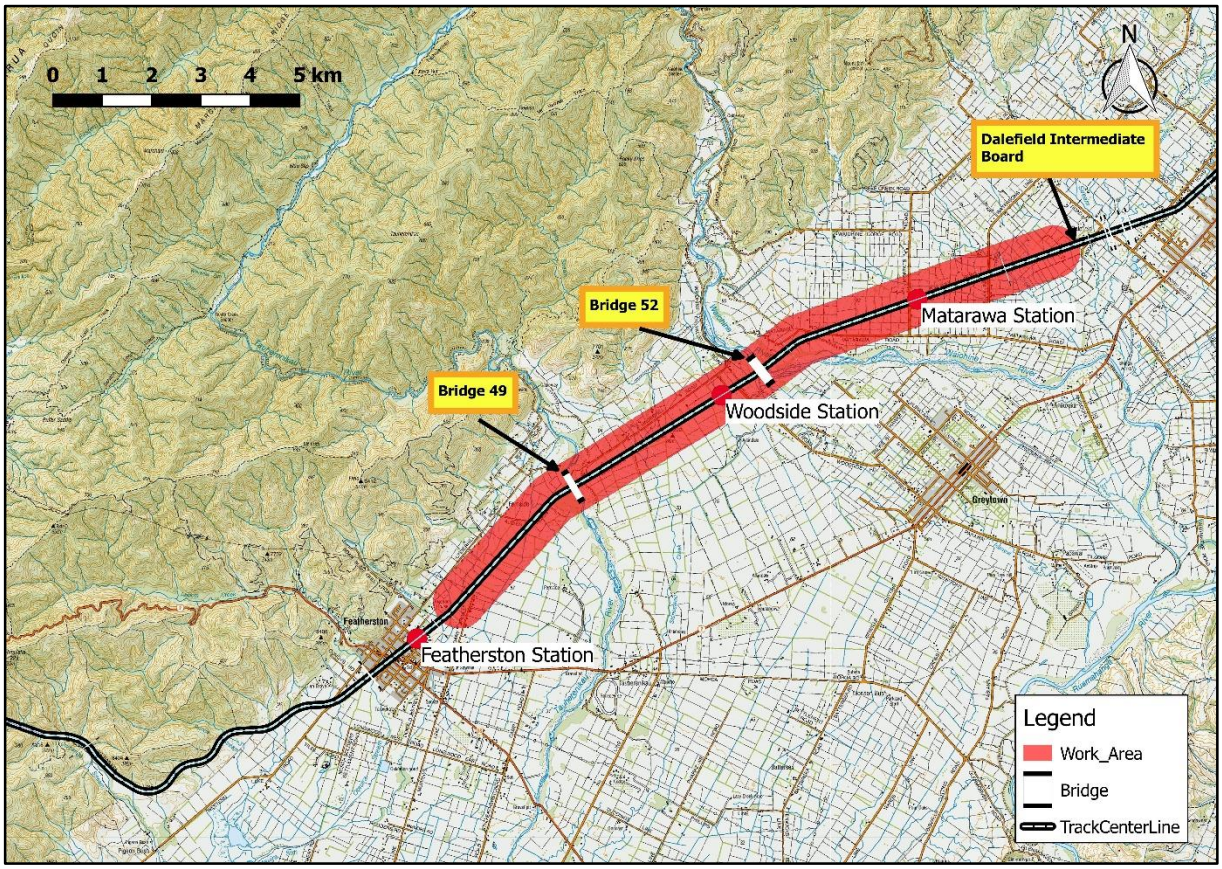


Figure 1
The protected work area

3.2.6. Earlier that day the Meteorological Service had issued a snowfall warning, forecasting that snow was likely to occur later that night on State Highway 2 between Featherston and Upper Hutt. Drivers were warned to take extra care in the winter driving conditions. Mindful of that warning, the rail protection officer left the worksite soon after he finished the safety briefing. He experienced snowfall near the summit of the Rimutaka Hill Road on his drive home.

3.2.7. After arriving home, he copied Track Warrant 88 and 'texted' the occupation authority to 14 addressees at 2337. He went to bed at 0115 and woke at about 0530.

3.2.8. A changeover of personnel at Bridge 49 and Bridge 52 took place at 0600. The rail protection officer phoned the incoming leading hand at Bridge 49 at 0642 to discuss the progress made during the night shift. He advised the leading hand that he could not drive to the bridge that morning because the road remained closed due to snowfall overnight. He then had a similar conversation with the leading hand at Bridge 52.

3.2.9. At 0647 he sent a group text to 14 addressees confirming that State Highway 2, Rimutaka Hill Road was closed because of the snowfall overnight. He then drove to his Wellington office and carried out general administrative work, returning home at about 1100.

3.2.10. The road controlling authority had re-opened Rimutaka Hill Road at 0953, so the rail protection officer then drove from home to Bridge 52, arriving at about 1300. He carried out a safety audit on the work group before reviewing their work progress with the leading hand. He then drove to the other worksite at Bridge 49 where he audited the Job Plan[8] book and discussed work progress with the on-site leading hand. He left the worksite at about 1500 to return home.

3.2.11. A scheduled shift hand-over took place at both worksites at 1800 and at 0600 the following day.

3.2.12. The rail protection officer reported that he slept for about nine hours on Saturday night before he woke at 0530. He attempted to communicate with the leading hand at Bridge 49 at 0823, but the cell phone was not answered.

3.2.13. After lunch he drove to the Bridge 49 worksite and then on to Bridge 52. Before he departed each worksite he instructed the leading hand that during their next hand-over at 1800, the incoming leading hand must be asked to phone him once the track had been cleared and was safe for trains to pass over.

3.2.14. After arriving home, he made a cell phone call to the structures field engineer at Bridge 52. They discussed the work progress and he was assured that the track would be cleared before the track warrant was due to be cancelled at 0300 the next day. The rail protection officer then forwarded a progress update text message to 12 addressees at 1649.

3.2.15. He went to bed at 1900 and woke at about 0245, having had what he described as a disturbed sleep.

3.2.16. At 0248:28 he made a cell phone call to the leading hand working at Bridge 49. The leading hand did not answer the call, so he left a voicemail message and followed up with a text message at 0248:45 requesting a return phone call.

3.2.17. The rail protection officer made a further cell phone call to another worker at Bridge 49 at 0249:53. Again the call was not answered so another request to return his call was made.

3.2.18. At 0251:18 he had a 40-second phone conversation with the structures field engineer who was off site at that time. The structures field engineer had left Bridge 52 at about 1900 the previous day after the work group had started to fix the rail to the replacement bridge sleepers. The structures field engineer told him that the phone of the leading hand at Bridge 49 had become saturated during the weekend and was no longer functioning. The structures

[8] The Job Plan book is a record to confirm that all rail personnel have been made aware of the hazards and understand the controls for the tasks being carried out.

field engineer commented to him that he could not confirm whether all works had been completed.

3.2.19. The rail protection officer made a further call to the leading hand at Bridge 52 at 0252:37, but again the call was not answered. A message was left asking him for a progress report.

3.2.20. At 0254:53 the rail protection officer phoned a third person who was at Bridge 49. When this call was not answered a further request to return his call was left as a voice message.

3.2.21. At 0255:11 the leading hand from the Bridge 52 worksite phoned the rail protection officer. He confirmed that the work group had left the worksite. He reported that all equipment was reported as clear of the track and that the bridge was safe for trains to pass over at the posted 25-kilometre-per-hour temporary speed restriction.

3.2.22. Despite not hearing from any members of the work group at Bridge 49, the rail protection officer phoned the train controller at 0259:33. He reported that all personnel and equipment were clear of the track and he 'handed back' Track Warrant 88. He confirmed that there was a 25-kilometre-per-hour temporary speed restriction over both bridges. The train controller asked whether the rail protection officer was at Featherston, to which he answered, "Yes".

3.2.23. Immediately after he handed back the track warrant he placed his cell phone beside his bed and was asleep within minutes.

3.2.24. At 0303 the train controller issued Track Warrant 5 to the driver of a repositioning passenger train at Featherston to proceed from the loop to Masterton. Clause 6 of the track warrant stated that the mainline had been reported clear at 0300.

3.2.25. At 0308 one of the workers at Bridge 49 responded to the rail protection officer's voicemail message, but the rail protection officer did not answer. He left a voicemail message for the rail protection officer stating that the work group was securing the last section of rail to the bridge sleepers and that they expected to be clear of the track within the next 30 minutes.

3.2.26. The repositioning train departed from Featherston at about 0313. At 0318 the driver was slowing his train for the 25-kilometre-per-hour temporary speed restriction across Bridge 49 when he saw flashing lights from a vehicle that appeared to be on track at the north end of the bridge. He stopped the train a few metres from the south end of the bridge, some 180 metres short of the hi-rail excavator and the work group that was occupying the track.

Figure 2
The approach to Bridge 49 from the south

3.2.27. The leading hand was startled by the approaching train. He believed that Track Warrant 88 was still active as he had not yet told the rail protection officer that the planned work had finished and the track had been cleared. He used the radio fitted to the hi-rail excavator to instruct the train driver to remain stationary until the track was cleared.

3.2.28. At 0321:32 the leading hand radioed the train driver and gave him a 'clear to proceed' instruction. The train driver stopped at the north end of the bridge at 0322:44 and alighted from the cab to converse with the work group. The train then continued towards Masterton.

3.2.29. As the train got underway the train driver radioed the train controller to inform him that he had come across the work group and equipment still on track at the north end of Bridge 49. The train controller immediately placed a block in the track warrant computer system[9] for the track section between Featherston and Dalefield to protect the work group before he authorised the train to proceed.

3.2.30. The train controller phoned the rail protection officer's cell phone at 0326:54, but the call was not answered, so he left a voicemail message asking him to call train control.

3.2.31. The leading hand at Bridge 49 phoned train control at 0342 to report that all work at the bridge had finished and that the bridge was safe for trains to pass over at the restricted speed of 25 kilometres per hour.

3.3. Key personnel

3.3.1. In accordance with KiwiRail procedures, the rail protection officer and all personnel on site at Bridge 49 at the time of the incident underwent post-incident drug and alcohol screening tests. All personnel returned negative results.

[9] The track warrant computer system is the system that allows a train controller to prepare and verify track warrants.

The rail protection officer

3.3.2. The rail protection officer's position with KiwiRail was 'corridor access co-ordinator' for the Central Region. Part of that role was to ensure safe rail corridor access and to support the region's planning and production manager in respect of worksite safety and general enquiries from external parties wanting to work within or near the rail corridor.

3.3.3. Rule 900 of the KiwiRail Track Safety Rules, effective from 6 October 2013, stated in part:

> ***Rail Protection Officer***
>
> *The person with overall responsibility for:*
>
> - *Providing rail protection for the Work Area with one or multiple work sites; the nature of the work sites and activity will determine the level of protection required.*
> - *Co-ordinating movement of all rail vehicles within and through the Protected Work Area.*
> - *Responsible for communicating with Train Control.*
> - *Where more than one work site is operating, Site protectors will report to the RPO [rail protection officer].*
>
> ***Note:***
>
> *RPO who is TPA 1.3 qualified are in charge of multi work sites within a Protected Work Area.*

3.3.4. Track Safety Rule 901, Job Planning, stated in part:

> ***g. Reporting the progress of work to Train Control***
>
> - *The RPO must report progress to Train Control at agreed times.*
> - *The work must be organised so that trains are not delayed unless previously agreed with Train Control.*
> - *Train Control must be advised of the time that normal train services may be reinstated and conditions under which trains may run.*
>
> ***h. Safe Place briefings***
>
> *Before work commences for the day and when the Work Site relocates, the Site Protector/RPO must brief all personnel on the "Safe Place[10]".*

3.3.5. The rail protection officer held current certification for the role he was performing. He was qualified to provide rail protection at a multi-worksite work area. His operating qualifications included:

- Track Protection Advanced 1.3 Multiple Worksites (TPA 1.3)
- Track Safety Rules – Course 2 (TPA)
- Track Warrant Control – Infrastructure Theory (P2).

3.3.6. The rail protection officer was a salaried employee with no fixed hours of duty. As such, he was not required to submit fortnightly timesheets. See Table 1 for details of the rail protection officer's work and rest hours in the week preceding the incident.

[10] A safe place is a place where people and equipment cannot be struck by passing rail traffic.

Date	Wake time	Hours worked	Bed time	Time spent in bed at night
Mon 4 August	0530	11 hrs	1900	9.5 hrs
Tues 5 August	0430	10 hrs	1900	10 hrs
Wed 6 August	0500	1 hr	1900	10.5 hrs
Thurs 7 August	0530	10.5 hrs	1900	10.5 hrs
Fri 8 August	0530	11 hrs (made up of a 7 hr block of work and a 4 hr block of work)	0115 (9th)	4.25 hrs
Sat 9 August	0530	8.5 hrs	1900	10.5 hrs
Sun 10 August	0530	8.5 hrs	1900	about 7.5 hrs

Table 1
Details of the rail protection officer's work and rest hours in the week preceding the incident

The train driver

3.3.7. The train driver's operating certificate was current at the time of the incident. His 30 years' driving experience included driving locomotive-hauled passenger trains on the Wairarapa Line for the previous 15 years.

3.3.8. He had read his train work orders and communicated with train control for an update on the sleeper replacement work before the train controller issued Track Warrant 5 to him at 0303.

The train controller

3.3.9. The train controller's certification was current for the tasks being undertaken. He had been on duty for 4.5 hours when the rail protection officer phoned to report that the planned work had finished and that trains could pass over the bridges at the posted speed of 25 kilometres per hour.

4. Analysis

4.1. Introduction

4.1.1. The safety of personnel working on the rail network is paramount. Failure to comply with any of the processes or procedures for providing protection can potentially result in a collision, as nearly happened in this case.

4.1.2. From a train control perspective, the train controller was entitled to issue the passenger train with a track warrant to pass through the area. He had had positive confirmation from the rail protection officer that he was on site and that the worksite was clear, although neither was the case.

4.1.3. The following analysis discusses three safety issues identified that were factors in this near collision:

- the process for planning and approving the worksite was not fully completed as required by KiwiRail processes
- the process for planning and approving the worksite allowed one person to carry out the rail protection duties over two separate worksites within a protected work area for a 52.5-hour track occupation period, with no relief
- there was insufficient management of the rail protection officer's day-to-day workload, which likely contributed to his being fatigued at the time he reported the track as clear, when it was not.

4.2. Protection of the worksite

4.2.1. KiwiRail's Operating Rule 401 (d) allowed for a track warrant to be issued to the rail protection officer. The warrant allowed work on or alongside the mainline without any other protection.

4.2.2. The role of the rail protection officer was created by KiwiRail in response to protection issues that had arisen, particularly at multiple worksites. The prime purpose of the role was to provide overall protection for a work area, co-ordinate rail movements within and through the protected work area and communicate with train control. Although all train movements had been suspended during the 52.5-hour work period, the activity still required hi-rail vehicle movements within the work area. The rail protection officer was responsible for ensuring that such movements were carried out in a safe manner.

4.2.3. At the time of the incident there was no specific instruction from KiwiRail that the rail protection officer was to remain at the site for the entire period of work. Feasibly, the work area could have been adequately protected without his presence, provided there was an agreed communication plan and provided the rail protection officer was present at crucial times. The ending of the worksite occupation and the handing back of the track to train control was considered a crucial time.

4.2.4. There were two separate work groups at each bridge site, working on a rotating basis. It was not possible for one person alone to fulfil the duties of the rail protection officer continually for more than two days. The need to relieve the rail protection officer was not identified at the planning stage or during the work phase, even though KiwiRail's Track Warrant Control Rule 410 had provision for such an event.

4.2.5. Critical to the events leading to this incident was the rail protection officer's location. Had he been located within the protected work area at the time that the track warrant was handed back he would have seen that the planned work at Bridge 49 was not complete, that personnel were still working in the area, and that it was unsafe for trains to pass.

4.2.6. Good railway practice would have given better guidance as to the level of presence required of the rail protection officer. Since this incident KiwiRail has introduced new Track Safety Rule 902, Managing a Protected Work Area and the associated Job Aid from January 2015 (see section 6).

4.2.7. New Track Safety Rule 902 (b) states in part:

> **Location of Rail Protection Officer**
>
> The RPO [rail protection officer] must remain in the limits of the Protected Work Area, unless the co-ordination of significant multiple work site activity is controlled from an approved location named on the Information Bulletin.
>
> **Job Aid**
>
> Rail protection personnel must be issued with the relevant *"Rule 902 Managing a Protected Work Area Job Aid"* and must have it available on site.

4.2.8. New Track Safety Rule 902 (n) states in part:

> **Handover of Protected Work Area/Work Site**
>
> When a Work Area and associated Work Sites are handed over between RPOs [rail protection officers], Assistant RPOs or SPs [site protectors] the procedures in the relevant *"Rule 902 Managing a Protected Work Area Job Aid"* must be applied.

4.2.9. Had this new rule been in place at the time and complied with, it is highly likely the incident would not have occurred.

4.2.10. The rail protection officer made his last site visit on Sunday 10 August. He left the protected work area at about 1500, 12 hours before the work was scheduled to be completed. At that time the sleeper replacement work at Bridge 49 was more advanced than that at Bridge 52.

4.2.11. Before he left the site the rail protection officer instructed the leading hands that during their 1800-changeover the incoming leading hands must be told to contact him when the track had been cleared the next morning, so that the track warrant could be cancelled. Relying on a verbal instruction given three hours before the leading hands were due to change over and approximately 12 hours before the track was likely to be clear was risky. There was some potential for them to forget to pass on the instructions to their reliefs and, even if the message were passed on, for the reliefs to forget to call the rail protection officer when the track was clear some nine hours later.

4.2.12. It would have been good practice for the rail protection officer to contact the incoming leading hands to confirm that they had both received the instruction to call him when the track was clear. Had he done so it might have raised some doubt as to whether the track was actually clear when he did not receive a call the following morning from the leading hand at Bridge 49, and could not make contact with him.

4.2.13. At 0245 the rail protection officer woke naturally before he called the leading hand at Bridge 49, but his call was not answered. At 0251 he called the structures field engineer who had left the worksite the previous evening. During their conversation he was made aware that the cell phone belonging to the leading hand at Bridge 49 was not functioning.

4.2.14. After a series of phone calls, the rail protection officer was provided with confirmation that the track was safe for trains to pass over Bridge 52, but he had no information in respect of the situation at Bridge 49. The rail protection officer made two further unsuccessful attempts to contact personnel at Bridge 49.

4.2.15. Handing back the track warrant that was protecting his worksite to train control without positively establishing that the work group at Bridge 49 was off and clear was a serious breach of KiwiRail rules, a breach that could have resulted in an accident.

4.2.16. When asked by the train controller whether he was on site at the time of giving clearance, the person in charge answered 'yes', when he was not. This answer is an indication that the person in charge knew and felt that he should have been there at the time. Some possible reasons for this behaviour are discussed in section 4.4.

4.3. Operating procedures (planning)

4.3.1. A failure to follow operating procedures at the planning stage of the work assignment resulted in the work group being under-resourced to manage the protection and safety of the work group effectively.

4.3.2. KiwiRail's procedures required applications for planned work that involved 'line impassable' to be submitted with at least 15 days' notice. While the regional planning team was aware of the need to replace sleepers on Bridges 49 and 52, the application for a line closure between Featherston and Dalefield from Friday 8 August to 0300 Monday 11 August gave only 10 days' notice. The submitter proposed that the work be carried out using KiwiRail's Track Warrant Control Rule 401 (d) to protect the multiple worksite activity.

4.3.3. Rule 401 (d) stated:

> *A track warrant may be issued to allow work on or alongside the mainline without other protection. A track warrant issued for other than trains must be addressed to the person responsible for safe working [the rail protection officer].*

4.3.4. KiwiRail's operating instructions for train control, clause 12.8.3, stated in part:

> *Where a track warrant is issued under this rule [401 (d)] the addressee, in addition to holding the appropriate current operating certificate must be able to be contacted by Train Control (e.g. have train control radio equipment) or be instructed to call Train Control at regular intervals as would be appropriate in the circumstances.*

4.3.5. KiwiRail Track Safety Rule 901 (e) stated in part:

> e. ***Communication Plan***
>
> *A Work Area Communication Plan must be prepared when:*
>
> - *The work area exceeds 1 km in length*
> - *When channel 1 radio coverage is not possible: the person planning protection must specify how communications will be managed*
> - *When there are multiple adjoining work sites protected by one RPO [rail protection officer]*
>
> *The Work Area Communication Plan must be submitted with the application for planned work, specifying how the RPO [rail protection officer] will communicate with protected personnel/operators and Drivers of Hi Rail vehicles.*

The application for the planned work was made by the rail protection officer. Although it was submitted later than the procedures stipulated, it was still accepted by KiwiRail Network Authorities and the information bulletin was issued, even though a communication plan was not attached.

Findings

1 The near collision between the train and the hi-rail excavator occurred because the rail protection officer informed train control that the worksite was clear without first checking positively that it was.

2 It would have exceeded the normal limitations of human performance for the rail protection officer to be on site for the entire 52.5-hour duration of the planned work. However, the release of the track warrant to end the track occupation was a safety-critical task that required the rail protection officer's presence at the worksite.

3	The KiwiRail process for planning and authorising the worksite was not entirely followed. The late application and the omission of a communication plan were factors contributing to the incident.

4.4. Fatigue

4.4.1. Did the rail protection officer have the opportunity to recover from sleep debt during the 52.5 hours he was performing his duties, and did the extended work period influence his decision to cancel the track warrant?

4.4.2. In the seven days leading up to the incident, the rail protection officer had had one day where his work commitments were limited. On all other days he had worked for more than eight hours and on four occasions 10 hours or more, resulting in a 60-hour work week (Table 1). He could not recall the last time that he had two consecutive days completely free of work, and regularly worked at weekends to catch up.

4.4.3. The Commission engaged Associate Professor Leigh Signal of the Sleep/Wake Research Centre at Massey University, New Zealand, to review the rail protection officer's work/rest patterns and lengths of shift and provide feedback as to whether fatigue would have likely contributed to the incident. On 22 September 2016 Associate Professor Signal and Doctor Lora Wu conducted an in-person interview with the rail protection officer.

4.4.4. Fatigue is a broad term often used to describe a wide range of symptoms. For this reason, there can be confusion about what 'fatigue' is and what the causes are. The approach used by Dr Signal for analysing the information was based on that developed by the United States National Transportation Safety Board and the National Aeronautics and Space Administration's Ames Canter's Fatigue Countermeasures Program, which focused on the physiological factors known to impair an individual's functioning. These physiological factors included **sleep loss** or **extended wakefulness**, **circadian biological clock** and **workload.** Appendix 4 gives a description of the terminology used by Associate Professor Signal.

The opinion of the sleep expert

The rail protection officer's general sleep pattern/recovery sleep

4.4.5. The rail protection officer normally went to bed at about 1900 and woke at 0500. At the time of the incident he often felt sleepy during the day and ate sweets to give himself energy. While it was not possible to determine whether he had a sleep disorder, his daytime sleepiness does suggest that the amount and/or quality of his sleep was not sufficient at the time of the incident.

4.4.6. In the week leading up to the incident he had spent Monday to Wednesday sleeping away from home. On those nights he had gone to bed at his usual time of 1900 but watched movies. It was not known when he went to sleep. He also stated that he had not slept as well as he normally did on those nights. While the amount of sleep he had obtained is unknown, it was likely less than he normally obtained.

4.4.7. On the afternoon of 8 August 2014 he had a nap of about 90 minutes before travelling to the worksite and starting the 52.5-hour shift. After returning home he might have obtained four hours' sleep at best, resulting in a 24-hour period during which he obtained substantially less sleep than he normally obtained and less than the recommended amount to maintain performance. Owing to his being on duty/on call, it is also possible that the quality of sleep he obtained on 9 and 10 August was adversely affected

4.4.8. The rail protection officer awoke naturally before starting to call various individuals at the two worksites. However, he was not certain of the time he woke and therefore the length of time between waking and handing back Track Warrant 88. He said that he placed the phone on its normal setting, beside his bed, after handing back the track warrant. He went back to sleep and did not wake in response to any of nine separate phone calls made to him from 0308:11 onwards. The rail protection officer made his first phone call after waking at 0632:46, some 90 minutes later than his normal wake time.

The rail protection officer's shift cycles

4.4.9. The rail protection officer had worked relatively long hours in the week leading up to the incident and had had no days completely free of work. The days and hours he had worked provided limited opportunity for recovery from any fatigue that may have built up through the hours worked, any sleep loss that may have built up over time, and the severe sleep loss experienced on the first night of the planned work.

The rail protection officer's length of shift

4.4.10. The rail protection officer was the only individual rostered to fill this role for the entire 52.5-hour work period. However, he did not remain on site throughout the work period. He visited the worksite at the start of the work period and returned home to sleep. He attended the worksite for a couple of hours on each of the next two days, but was not on site at the critical time to confirm that the protected work area was clear and the track was safe for the passage of trains before handing back the track warrant.

4.4.11. It was not possible for one person to fulfil the role and responsibilities of the rail protection officer for a continuous 52.5 hours without relief.

Was fatigue likely to have contributed to the incident?

4.4.12. For an incident or accident to be defined as fatigue related, it must have both:

- occurred in the presence of fatigue, and
- been consistent with a fatigue-related error (i.e. caused by falling asleep, inattention, delayed reaction time or error in judgement).

4.4.13. The rail protection officer was likely experiencing fatigue during the early hours of Monday 11 August 2014, caused by a number of factors including his:

- relatively high workload and long work days in the week leading up to the incident
- excessively long duty work period of 52.5 hours following a full work week
- possible sleep restriction on Monday 4 August through to Wednesday 6 August
- severe sleep restriction on Friday 8 August
- lack of opportunity to recover from this sleep restriction before the planned work period
- need to perform work-related duties during his biological night when he would normally be asleep.

4.4.14. The impaired judgement of the rail protection officer, which included making the incorrect assumption that the work had been completed and the track was clear, was consistent with fatigue-related performance. He was also required to perform these tasks at an adverse circadian phase (see Appendix 4). For an individual with normal circadian phase and normal sleep timing, poorest performance would typically be at around 0400. However, given the rail protection officer's possible circadian preference of extreme morning type, it is very likely that he handed back the track warrant during his individual circadian low point in performance.

4.4.15. In addition, the rail protection officer may have experienced sleep inertia that contributed to his impaired judgement in the early hours of Monday 11 August. Sleep inertia has been shown to be more severe for tasks that involve decision-making, when prior sleep restriction is experienced and in the early hours of the morning. This incident did involve decision-making, the rail protection officer's sleep was likely to have been restricted in the week leading up to the incident, and the track warrant handback occurred in the early hours of the morning.

4.4.16. The combination of the time of day, likely underlying level of fatigue, and sleep inertia contributed to the errors.

4.4.17. Given the factors that likely contributed to the rail protection officer's level of fatigue, a recommendation has been made to the Chief Executive of KiwiRail to address the company's Fitness for Work Policy.

Findings

4 It was likely that the rail protection officer was affected by an underlying level of fatigue and sleep inertia when he made the incorrect assumption that the work had been completed and the track was safe for trains to pass over.

5 KiwiRail was not effectively managing the rail protection officer's day-to-day workload, which was likely a factor contributing to an underlying level of fatigue at the time of the incident.

5. Findings

5.1. The near collision between the train and the hi-rail excavator occurred because the rail protection officer informed train control that the worksite was clear without first checking positively that it was.

5.2. It would have exceeded the normal limitations of human performance for the rail protection officer to be on site for the entire 52.5-hour duration of the planned work. However, the release of the track warrant to end the track occupation was a safety-critical task that required the rail protection officer's presence at the worksite.

5.3. The KiwiRail process for planning and authorising the worksite was not entirely followed. The late application and the omission of a communication plan were factors contributing to the incident.

5.4. It was likely that the rail protection officer was affected by an underlying level of fatigue and sleep inertia when he made the incorrect assumption that the work had been completed and the track was safe for trains to pass over.

5.5. KiwiRail was not effectively managing the rail protection officer's day-to-day workload, which was likely a factor contributing to an underlying level of fatigue at the time of the incident.

6. Safety actions

General

6.1. 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.

Safety actions addressing safety issues identified during the inquiry

6.2. KiwiRail's Operating Rule 910, Work Arrangements Multiple Activities, has been discontinued and replaced by Rule 902 Managing a Protected Work Area, together with Rule 902 Managing a Protected Work Area Job Aid. The KiwiRail Track Safety Rules, Issue 3, which included new site safety Rule 902, was effective from 30 June 2015. Rule 902 is referred to as a 'lock on, lock off' procedure.

6.3. On arrival at a protected work area all personnel, including the rail protection officer, contractors and visitors, must sign a worksite register TS90 form, to confirm that they have been briefed on and understand the protection method, the worksite limits, the safe place, the rail hazards and the need to report to the rail protection officer before leaving the worksite (see Figure 3). All vehicles likely to operate on the track are entered on the register by the drivers and include the vehicle radio 'call signs'.

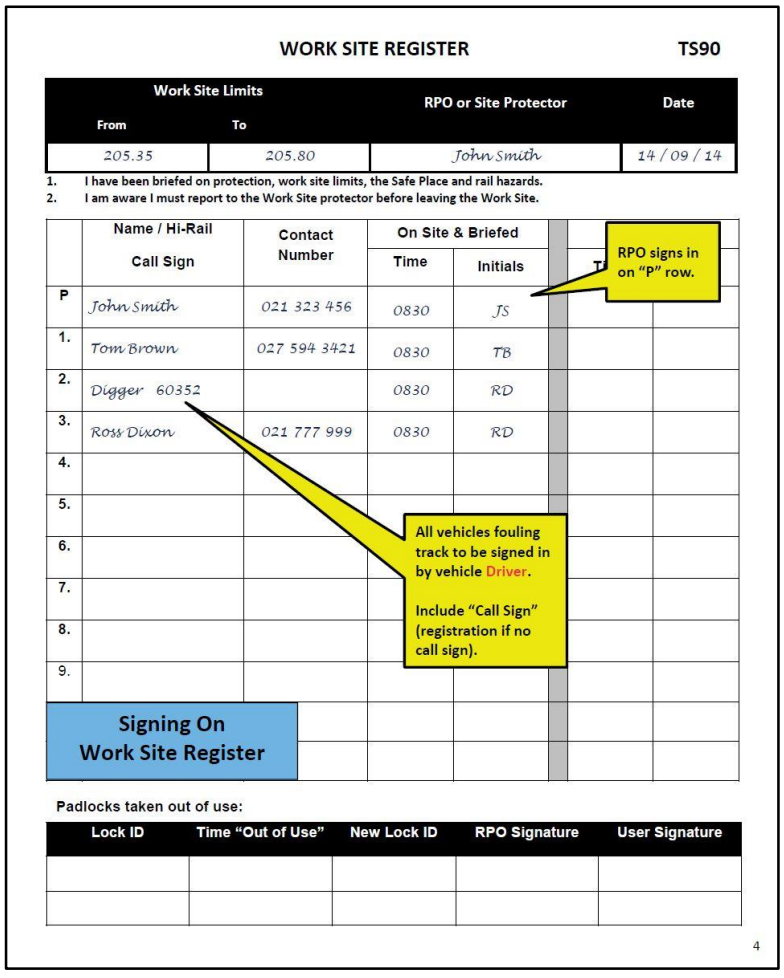


Figure 3
Worksite register

6.4. All personnel and machinery entered on the worksite register are allocated padlocks that are locked on to a numbered aluminium frame before leaving the safe place (see Figure 4). The padlocks are colour coded: green for the rail protection officer, orange for workers trained under Rule 902, blue for visitors and workers not trained in the procedures (but given instructions on arrival) and black for hi-rail vehicles and equipment on track. The lock-on frame is not made available for lock-on until the rail protection officer has entered a worksite 'start' time on the Protected Work Area Logbook form, TS92. The rail protection officer must attach their green padlock to the frame handle before making it available to others to lock on. Personnel/Vehicle padlocks must be secured in the same slot numbers as recorded in the worksite register. All personnel/vehicles must be locked on before leaving the safe place.

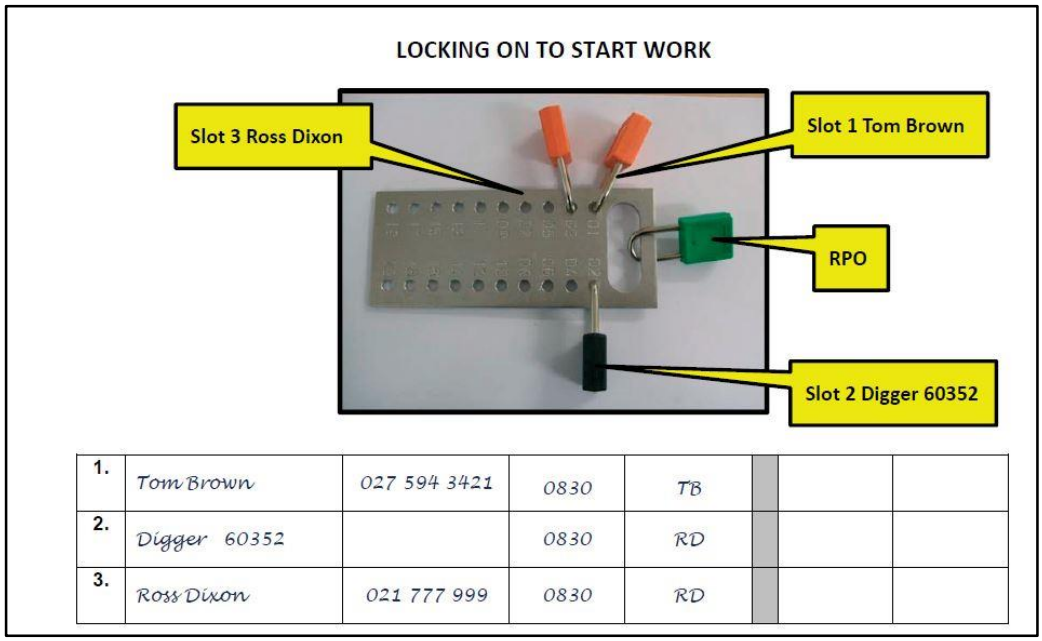


Figure 4
Locking on to start work

6.5. The lock-on frame must not be made available for lock off until the rail protection officer has returned to the safe place, all vehicles have been secured in a safe mode clear of the track and all personnel, including visitors, have returned to the safe place. The rail protection officer must not remove their green padlock until all other padlocks have been removed. The rail protection officer must then show the clear lock-on frame to personnel in the safe place before authorising rail movements or cancelling the protection authority. At least one other person must acknowledge the clear frame. The rail protection officer must maintain a view of the track and the safe place until the movement passes.

6.6. A rail protection officer can only clear the protection authority when all padlocks have been removed and all personnel have signed off the worksite register.

6.7. On 8 August 2016 KiwiRail issued a Toolbox Topic, Consultation Document Change Proposal for Track Protection. The document showed how KiwiRail intended to reduce the frequency of track occupation incidents by training and appointing dedicated rail protection officers and separating their duties from those of a work supervisor/team leader/leading hand.

6.8. Since this incident KiwiRail has established the role of protection planner. This position provides a level of independent scrutiny of worksite protection arrangements and ensures that the protection services required is realistic and achievable.

7. Recommendation

General

7.1. 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, one recommendation has been issued to the Chief Executive of KiwiRail.

7.2. In the interests of transport safety, it is important that this recommendation is implemented without delay to help prevent similar accidents or incidents occurring in the future.

Recommendation made to KiwiRail

7.3. The approval process authorised one person to carry out the rail protection duties for two separate worksites within a protected work area throughout a 52.5-hour track occupation period without appointing a relief rail protection officer. The rail protection officer had worked relatively long hours during the week leading up to the incident and had had no days completely free of work. His working hours had provided limited opportunity for recovery from any fatigue or sleep loss that may have built up, and particularly sleep loss that he experienced on the first night of the planned work.

On 28 June 2017 the Commission recommended that the Chief Executive of KiwiRail review the company's Fitness for Work Policy to ensure that the workloads of personnel undertaking safety-critical work, including staff not on a roster, are managed effectively and that the risk of their suffering from the effects of fatigue is mitigated. (017/17)

7.4. On 14 July 2017 KiwiRail replied:

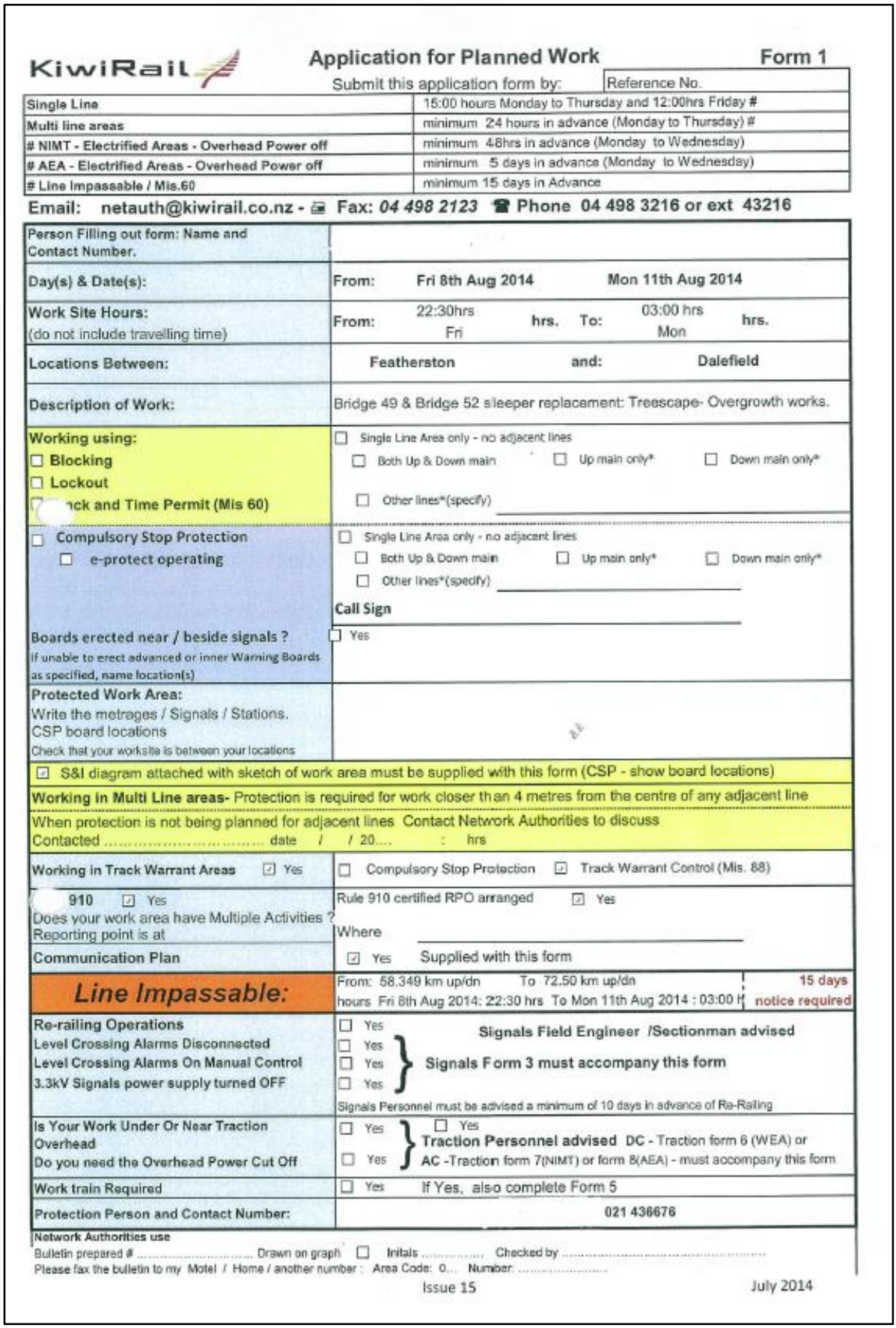
> KiwiRail confirms that it accepts the intent of recommendation 017/17 and it will now scope the required compliance requirements and undertake the actions required to allow closure of the recommendation. Starting at the corporate level, this will require the implementation of a business-wide policy that will ensure that management control measures are developed and adopted across the business to ensure that personnel performing safety-critical functions have their workloads managed to ensure they don't potentially suffer the effects of fatigue, which could contribute towards unsafe actions, behaviours or decisions being made.

8. Key lessons

8.1. Not following standard railway operating procedures that are designed to provide for safe railway operations is highly likely to result in an accident.

8.2. Decisions that can affect the safety of railway workers should never be based entirely on assumptions, as in this case when clearance was given for trains to pass through the area when workers were still occupying the track.

Appendix 1: Application for Planned Work



KiwiRail

Application for Planned Work **Form 1**

Submit this application form by: Reference No.

Single Line	15:00 hours Monday to Thursday and 12:00hrs Friday #
Multi line areas	minimum 24 hours in advance (Monday to Thursday) #
# NIMT - Electrified Areas - Overhead Power off	minimum 48hrs in advance (Monday to Wednesday)
# AEA - Electrified Areas - Overhead Power off	minimum 5 days in advance (Monday to Wednesday)
# Line Impassable / Mis.60	minimum 15 days in Advance

Email: netauth@kiwirail.co.nz - Fax: *04 498 2123* Phone 04 498 3216 or ext 43216

Person Filling out form: Name and Contact Number.	
Day(s) & Date(s):	From: Fri 8th Aug 2014 Mon 11th Aug 2014
Work Site Hours: (do not include travelling time)	From: 22:30hrs Fri hrs. To: 03:00 hrs Mon hrs.
Locations Between:	Featherston and: Dalefield
Description of Work:	Bridge 49 & Bridge 52 sleeper replacement: Treescape- Overgrowth works.
Working using: ☐ Blocking ☐ Lockout ☐ ck and Time Permit (Mis 60)	☐ Single Line Area only - no adjacent lines ☐ Both Up & Down main ☐ Up main only* ☐ Down main only* ☐ Other lines*(specify)
☐ Compulsory Stop Protection ☐ e-protect operating	☐ Single Line Area only - no adjacent lines ☐ Both Up & Down main ☐ Up main only* ☐ Down main only* ☐ Other lines*(specify) Call Sign
Boards erected near / beside signals ? If unable to erect advanced or inner Warning Boards as specified, name location(s)	☐ Yes
Protected Work Area: Write the metrages / Signals / Stations. CSP board locations Check that your worksite is between your locations	
☑ S&I diagram attached with sketch of work area must be supplied with this form (CSP - show board locations)	
Working in Multi Line areas- Protection is required for work closer than 4 metres from the centre of any adjacent line	
When protection is not being planned for adjacent lines Contact Network Authorities to discuss Contacted ..... date / / 20.... : hrs	
Working in Track Warrant Areas ☑ Yes	☐ Compulsory Stop Protection ☑ Track Warrant Control (Mis. 88)
910 ☑ Yes Does your work area have Multiple Activities ? Reporting point is at	Rule 910 certified RPO arranged ☑ Yes Where
Communication Plan	☑ Yes Supplied with this form
Line Impassable:	From: 58.349 km up/dn To 72.50 km up/dn 15 days hours Fri 8th Aug 2014: 22:30 hrs To Mon 11th Aug 2014 : 03:00 H notice required
Re-railing Operations ☐ Yes Level Crossing Alarms Disconnected ☐ Yes Level Crossing Alarms On Manual Control ☐ Yes 3.3kV Signals power supply turned OFF ☐ Yes	Signals Field Engineer /Sectionman advised Signals Form 3 must accompany this form Signals Personnel must be advised a minimum of 10 days in advance of Re-Railing
Is Your Work Under Or Near Traction Overhead ☐ Yes Do you need the Overhead Power Cut Off ☐ Yes	☐ Yes Traction Personnel advised DC - Traction form 6 (WEA) or AC -Traction form 7(NIMT) or form 8(AEA) - must accompany this form
Work train Required	☐ Yes If Yes, also complete Form 5
Protection Person and Contact Number:	021 436676

Network Authorities use

Bulletin prepared # ..... Drawn on graph ☐ Initals ..... Checked by .....

Please fax the bulletin to my Motel / Home / another number : Area Code: 0... Number: .....

Issue 15 July 2014

Appendix 2: Information bulletin dated 8 August 2014

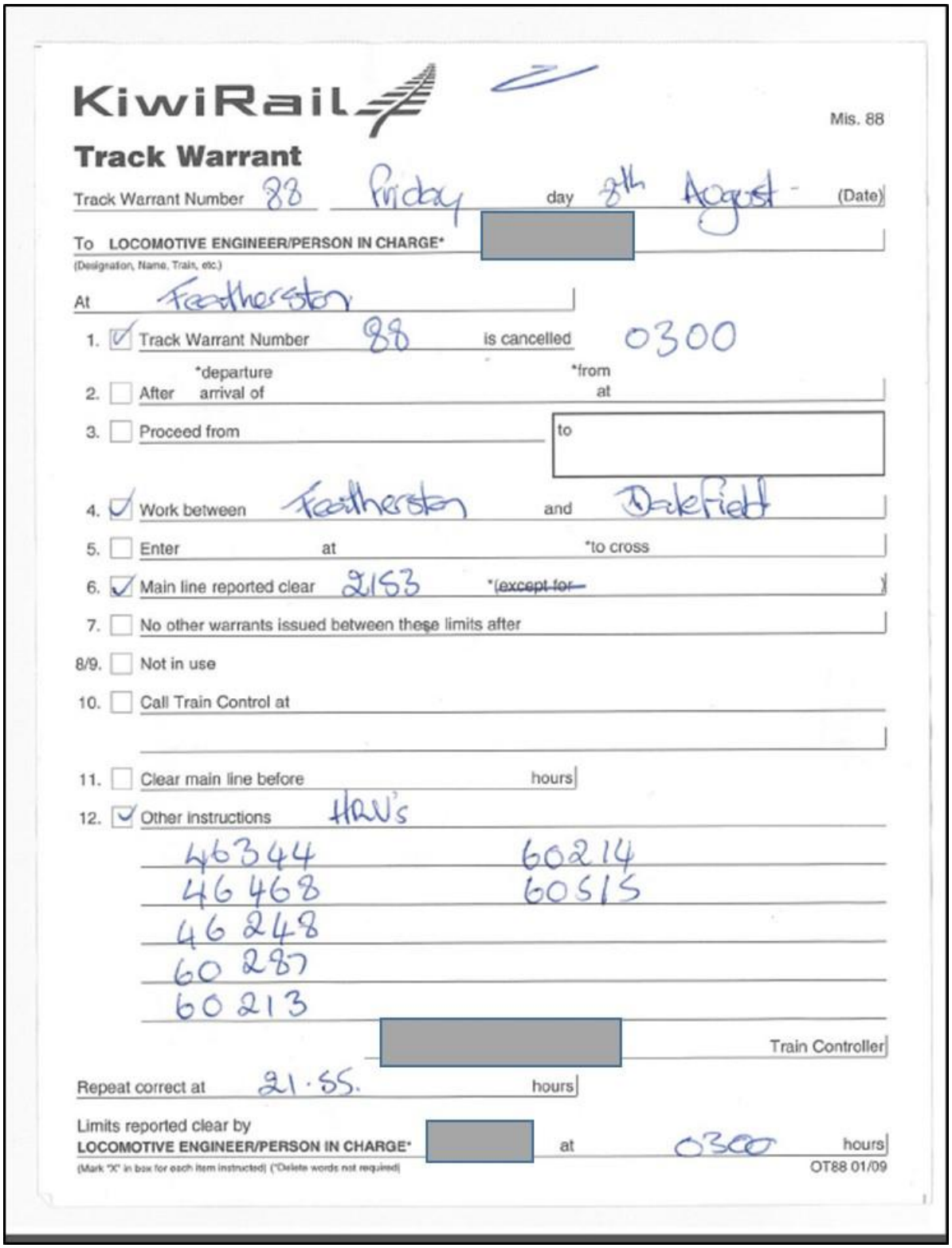
	Friday 8 August 2014 Wellington – Waikanae, Johnsonville Line Wellington Junction – Masterton and Branches

Wellington Junction – Masterton and Branches

Protected Work Area		Rule	Work Details
14.46 km Woburn Up & Down lines	25.10 km Silverstream Up & Down lines	**905** Compulsory Stop Protection	Traction Maintainence 2300 previous day to 0500 021 246 2013 Call sign: **Oscar Hotel Charlie**
Caution – Rule 905(c) applies. No Advanced / Inner Warning Board(s) exiting Gracefield Branch. Compulsory Stop boards erected at 0.23km, All Trains Stop board for services entering Woburn Sidings from Gracefield Branch. **The overhead power** will be cut off between Woburn Substation at 14.50 km and Silverstream Substation at 25.15 km. Hours: 0001 to 0430, Up & Down lines			
65.30 km Woodside	69.50 km Matarawa	**905** Compulsory Stop Protection	Bridge 52 Works 0730 – 1600 027 221 8466 Call sign: **Delta November Alpha**
Up Advanced Warning Boards Erected at 62.50km.			
Matarawa	Waingawa	**TW 401 d**	Mulching and Tree Removal 0730 - 1630 T Moran, 027 711 1221
Featherston	Dalefield	**TW 401 d**	**Multiple Activities: Rule 910** • Bridge 49 Works, • Bridge 52 sleeper replacement • Overgrowth removal 2230 **Fri** to 0300 **Mon** 021 436 676
Line Impassable: Line impassable between the above points during the hours of work.			

Senior Network Access Planner

Appendix 3: Track Warrant 88



KiwiRail

Mis. 88

Track Warrant

Track Warrant Number 88 Friday day 8th August (Date)

To LOCOMOTIVE ENGINEER/PERSON IN CHARGE* [redacted]
(Designation, Name, Train, etc.)

At Featherston

1. ☑ Track Warrant Number 88 is cancelled 0300
2. ☐ After *departure / arrival of *from / at
3. ☐ Proceed from to
4. ☑ Work between Featherston and Dakefield
5. ☐ Enter at *to cross
6. ☑ Main line reported clear 2153 *(except for)
7. ☐ No other warrants issued between these limits after
8/9. ☐ Not in use
10. ☐ Call Train Control at
11. ☐ Clear main line before hours
12. ☑ Other instructions HRV's

46344 60214
46468 60515
46248
60287
60213

[redacted] Train Controller

Repeat correct at 21.55. hours

Limits reported clear by
LOCOMOTIVE ENGINEER/PERSON IN CHARGE* [redacted] at 0300 hours

(Mark "X" in box for each item instructed) (*Delete words not required)

OT88 01/09

Appendix 4: Extract from report provided by Associate Professor TL Signal, Dr L Wu and Dr J Zalona, Sleep/Wake Research Centre, Massey University, New Zealand

Sleep loss

Sufficient good quality sleep is vital to sustaining normal levels of functioning. The amount of sleep required on a daily basis varies from one individual to the next, with the recommended amount between 7-9 hours for a healthy adult, although some individuals may require as little as 6 hours of sleep and others as much as 10 hours. When a short term or long term change in sleep results in less or poorer quality sleep than an individual's ideal daily sleep need, a sleep debt is said to occur and accrue.

Acute sleep loss

It has been shown that curtailing the usual amount of sleep for one night by as little as 2 hours produces measurable increases in sleepiness while decrements in performance are most apparent once sleep is restricted to 5 hours or less in a single night. It is not only the amount of sleep obtained, but also the quality of sleep that is important. One night of disturbed sleep (sleep that is lighter and fragmented by awakenings) is also related to increased sleepiness and decreased performance and mood the following day.

Chronic sleep restriction

When sleep is restricted or disturbed for more than one night, the effects accumulate and a sleep debt builds. These effects are also dose-dependent, so that with greater nightly sleep restriction, performance and mood decline more rapidly.

In a study that involved 4 groups of people who, across a week of sleep restriction, were either allowed 9 hours, 7 hours, 5 hours or 3 hours in bed each night. The groups spending 5 or 7 hours in bed each night became progressively slower for the first 5 days after which their performance appeared to stabilise. The performance of those who spent 3 hours in bed each night declined steadily across all 7 days. In this study, subjective sleepiness also increased across the first few days of sleep restriction but then tended to stabilise, although performance continued to decline. Thus, individuals tend to underestimate the extent to which their performance is affected when sleep is chronically restricted.

After periods of sleep restriction (e.g. 2 weeks of only 6 hours in bed), performance is equivalent to that seen under conditions of total sleep deprivation (e.g. no sleep for 24 hours), indicating that chronic partial sleep restriction can induce deficits in the waking brain that are similar to total sleep deprivation.

More recent studies have shown that chronic sleep restriction interacts with time-of- day (circadian phase), resulting in the poorest performance during the biological night.

Shortening a sleep opportunity will result in restricted sleep but it is also possible for an individual to spend sufficient time in bed and still not obtain enough sleep. Many factors can disrupt sleep but two issues of particular relevance are noted here. The first of these is that sleep may be impaired when an individual expects they may be called back to work. In such instances the amount of sleep obtained as well as the quality may be reduced. The literature in this area is, however, very limited.

Sleep disorders are also of relevance due to their impact on the quantity and quality of sleep an individual is able to obtain and their potential impact on waking functioning including impaired performance, increased risk of accidents or incidents while driving, sleepiness, poor mood and poorer social adjustment. There are a large number of sleep disorders, some of which are relatively common in the New Zealand population including sleep apnoea, insomnia, circadian rhythm disturbances and movement-related sleep disorders. Physical and psychological health conditions, particularly those that result in pain, discomfort or anxiety, can also result in disturbed sleep.

Recovery from chronic sleep restriction

A single night of recovery sleep is not considered sufficient to compensate for fatigue that has built up over an extended period of time, even if that recovery sleep is extended to 10 hours in bed. After chronic sleep restriction, at least two consecutive nights of unrestricted sleep are required for the structure of sleep to return to normal, with more slow-wave sleep than usual during the first night of recovery sleep, and more REM (dream) sleep than usual in the second night of recovery sleep. By the third night of recovery sleep, the structure of sleep usually returns to normal.

However, the recovery of waking functioning may take longer than this. In the study mentioned above], it was noted that performance did not recover back to baseline even after 3 nights of 8 hours per night in bed. This suggests that chronic sleep restriction leads to long term and constant changes in functioning that may help an individual adapt to the effects of continued sleep restriction. However, these changes come at a cost, so that when sleep duration is extended and recovery allowed, a return to baseline levels of alertness and performance does not occur immediately.

A recent study has shown that even 5 nights of 8 hours' recovery sleep was not sufficient to return performance to that seen prior to 7 nights of restricted sleep, but performance did recover more rapidly in individuals who had extended their sleep prior to the week of sleep restriction.

Expert working groups in trucking have recommended that at least two full nights of unrestricted sleep are required on a regular basis (preferably weekly) so that a significant sleep debt cannot accrue. Unrestricted night time sleep refers to an individual being able to go to bed and rise when they choose, with the sleep period overlapping the circadian period most conducive to sleep (see the section below on circadian phase for further explanation).

Extended wakefulness

It has been demonstrated that 8-hours of night time sleep provides about 16 hours of day time wakefulness, after which decrements in performance appear. To quantify the relative risk of impaired performance caused by sleep loss, a number of studies have compared the effects of staying awake for extended periods to the effects of alcohol on performance. It has been shown that after an 0800 wakeup, 17 hours of sustained wakefulness across the biological night, leads to performance decrements equivalent to that observed when an individual is at the legal limit for blood alcohol concentration. Several other studies also demonstrate that sleepiness increases with extended wakefulness.

Circadian phase

Humans have peaks and troughs in daily functioning across a range of physiological and behavioural variables, including temperature, hormone levels, the sleep-wake cycle, mood and performance. These daily variations are controlled by a group of cells located in the brain referred to as the circadian biological clock. The circadian clock effectively "programmes" us for wakefulness during the day and sleep at night and keeps in step with the earth's 24-hour day-night cycle because it is sensitive to environmental cues, particularly exposure to light.

Due to the circadian biological clock, sleepiness is maximal in the early hours of the morning (approximately 3-5am) with another, smaller peak in the middle of the afternoon (approximately 3-5pm) (see figure below). Although maximal sleepiness is in the early hours of the morning, performance and alertness can be affected throughout the night hours when a person would normally be asleep.

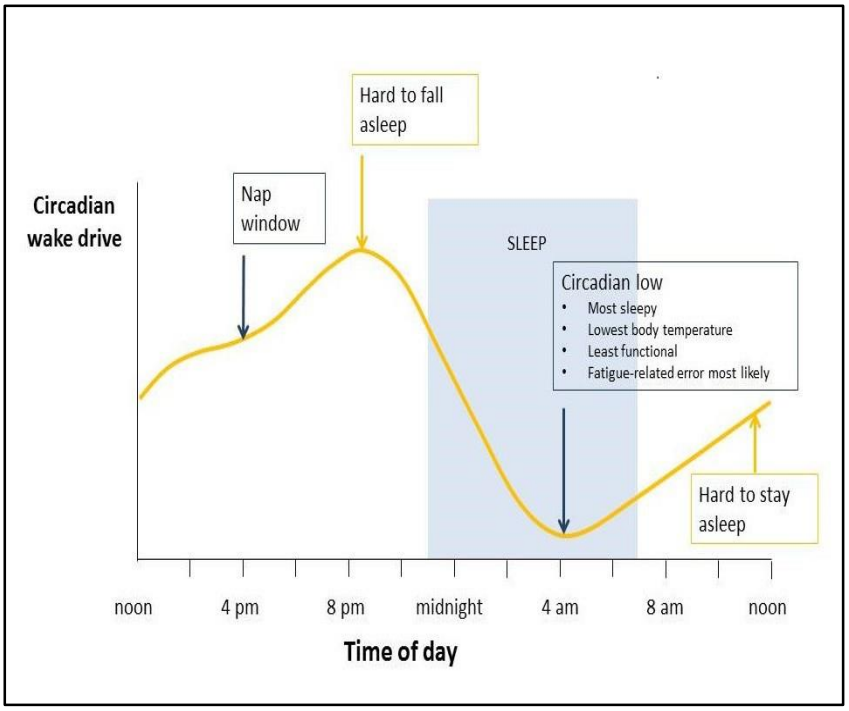


Figure 5
The influence of circadian body clock on sleep and alertness where an individual typically sleeps between 2300 and 0700

The circadian system also helps maintain wakefulness during the day, making it difficult for individuals who are working at night and sleeping during the day to obtain sufficient good quality sleep. Night shifts are not the only mechanism through which a sleep debt can accumulate. Early morning starts that truncate night time sleep can also shorten sleep significantly and although individuals may attempt an earlier bed time in "preparation" for an early start, the circadian biological clock promotes wakefulness in the few hours before a person's habitual bedtime making it difficult to fall asleep earlier than usual.

There are known differences in the timing of the circadian system between individuals. These differences have a physiological basis but are also influenced by factors such as work patterns, and social and family commitments. Morning types go to bed early and rise early whereas evening types go to bed later and rise later. The prevalence of very morning or evening oriented individuals is not well established but using a range of definitions, a New Zealand study has shown that the proportion of the population reporting being an extreme morning type ranges between <0.5%-9%, and an extreme evening type between <0.5%-10%.

The effects of the circadian body clock cycle and sleep restriction interact: performance decrements resulting from sleep restriction are greater during the part of the circadian cycle when sleep would normally occur, even after short prior wake durations.

Changes in cognitive performance with fatigue

There is often debate as to how well the performance changes seen on laboratory tasks, such as those discussed in the above studies, relate to "real world", or more cognitively complex, performance.

Higher-order cognitive skills are thought to be reliant on the functioning of the prefrontal region of the cerebral cortex and recent evidence has shown that this area of the brain is affected by as little as one night of sleep loss. Both simple and complex cognitive tasks show deficits following sleep restriction including sustained attention and reaction time, working memory and cognitive throughput. Harrison and Horne discuss evidence that suggests a raft of higher level cognitive skills are adversely affected by sleep loss. Those affected include: attending to complex information while filtering out distractions, following a situation and recognising the need to apply new strategies, lateral thinking and innovation, risk assessment, maintaining interest, controlling mood and behaviour, the ability to self- monitor performance, and the ability to communicate effectively.

Sleep Inertia

One additional factor that deserves mention in the current context is sleep inertia. Sleep inertia is a well-documented phenomena and is a period of confusion, grogginess, low arousal and reduced functioning experienced immediately on awakening. It can cause performance impairment that is worse than just before bedtime, when an individual would be expected to be more fatigued.

The process of waking up is not an on/off switch. A brain imaging study suggests that different parts of the brain reactivate at varying rates, and that functional connectivity among different brain regions needs to be reorganised to achieve a fully awake brain state. Activity in the brain regions that are associated with arousal returns very quickly during the waking process, whereas reactivation of the pre-frontal cortex, the brain region associated with higher-order cognitive functioning, takes longer.

A number of factors can influence the severity and duration of sleep inertia, including the type of cognitive task performed upon awakening. The effects of sleep inertia can last from a minute to several hours, with longer-lasting effects on more complex cognitive tasks, such as decision-making. Research has also shown that the effects are greater following sleep restriction or when woken in the middle of the night. The effects of sleep inertia may also be greater after waking from slow-wave sleep but are less severe when woken from REM (dream) sleep.

Sleep inertia research has predominantly involved young adults and limited evidence suggests that older adults may be more susceptible to the effects of sleep inertia than their younger counterparts.

To reduce the risk of impaired decision-making, it is suggested to allow at least 10-15 minutes after waking for sleep inertia to dissipate before undertaking critical tasks.

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Price $16.00

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