Report 00-121

express freight Train 828 and express freight Train 951

collision

Middleton

8 December 2000

Abstract

At about 0400 on Friday 8 December 2000, Train 828, a northbound express freight train, passed Signal 212 at Middleton at "Stop" and collided head-on with departing southbound express freight Train 951.

Three locomotive crew members received minor injuries. The locomotive on each train and a number of wagons were extensively damaged.

Safety issues identified included the control of locomotive engineers hours of duty, fatigue management and the ability of the locomotive vigilance system to overcome short-term attention deficits in time to prevent this type of collision.

In view of safety recommendations made to the operator in other Rail Occurrence Reports 00-115 and 00-117 relating to previous occurrences involving similar attention loss through microsleeps, no further safety recommendations were made to the operator.

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.

Transport Accident Investigation Commission
P O Box 10-323, Wellington, New Zealand
Phone +64 4 473 3112 Fax +64 4 499 1510
E-mail: reports@taic.org.nz Web site: www.taic.org.nz

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Abbreviations

k	kilometre(s)
km/h	kilometres per hour
LE	locomotive engineer
LE1	locomotive engineer Train 828
LE2	locomotive engineer Train 951
m	metre(s)
t	tonne(s)

Data Summary

Train type and number:	express freight Train 828 and express freight Train 951		
Date and time:	8 December 2000 at about 0400		
Location:	Middleton		
Type of occurrence:	collision		
Persons on board:	crew	Train 828	1
		Train 951	2
Injuries:	Train 828	1 minor	
	Train 951	2 minor	
Damage:	the locomotives and several wagons on each train were extensively damaged		
Operator:	Tranz Rail Limited (Tranz Rail)		
Investigator-in-charge:	D L Bevin		

1. Factual Information

1.1 Narrative

1.1.1 On Friday 8 December 2000 Train 828 was a Greymouth to Middleton express freight service and consisted of locomotive DX5229 and 19 bogie wagons. The train weight was 853 t with a length of 346 m and was crewed by a locomotive engineer (LE1).

1.1.2 LE1 commenced duty in Middleton at his rostered time of 2150 hours on Thursday 7 December 2000 and departed at 2300 on a Middleton to Greymouth express freight service, which was his rostered job. He travelled to Cass on the Midland Line where he changed over to Train 828 and departed from Cass at about 0130 on Friday 8 December 2001 for his return trip to Middleton.

1.1.3 Train 828 joined the Main South Line at Rolleston[1], about 17 km south of Middleton, and LE1 recalled that he crossed Train 823 at Rolleston. LE1 said that he slowed for a speed restriction at Hornby, about 3.5 km from Middleton, then remembered passing Mainfreight Siding about 1200 m from Middleton where he saw a "caution normal speed " (yellow) indication on Signal 1712, a stop-and-stay intermediate signal which was mounted on an overhead gantry spanning the tracks. This advised LE 1 that the section ahead was clear but that the next signal in advance (Signal 212) was at "Stop" or displaying a low-speed indication.

1.1.4 The next thing LE1 remembered was when he "sort of woke up underneath the Curletts Road overbridge". He thought he had been asleep for about 400 m and estimated he was about 450 m from Signal 212 when he realised it was displaying a "Stop" (red) indication. There was also no low speed light illuminated. LE1 recalled making an immediate emergency brake application while at the same time he saw the headlight of Train 951 as it entered the up main line on which he was travelling. He realised his train would not stop before Signal 212 and that a collision was imminent so he braced himself against the driver console to prepare for the impact.

1.1.5 Train 951 was a Middleton to Timaru express freight service and consisted of DX5235 and 39 bogie wagons. The train weight was 878 t with a length of 659 m and was crewed by a locomotive engineer (LE2) and a rail operator.

1.1.6 LE2 commenced duty in Middleton at his rostered time of 0035 on Friday 8 December 2000 to run Train 951 to Timaru, returning to Middleton by car. At about 0300 he boarded his locomotive at the servicing depot and attached it to his train in the yard. He was joined in the locomotive cab by the rail operator, who was rostered to travel to Timaru on the train to assist with shunting duties enroute.

1.1.7 At about 0330 the signalman in Addington signalbox was advised by the train controller that Train 828 had passed through Rolleston enroute to Middleton. The signalman said that LEs of approaching trains often called him by radio between Rolleston and Middleton but there was no requirement for them to do so and LE1 had not done so on that occasion.

1.1.8 The signalman knew that Train 951 was nearly ready to depart so he called the operations office at Middleton to see if the yard staff wanted Train 828 to berth before or after Train 951 departed. In response to his call the operations controller, or the train examiner operations, he couldn't remember who, told him that there was no road on which to berth Train 828 until Train 951 had departed.

[1] Rolleston was a junction station where the Midland Line and the Main South Line diverged.

1.1.9 About this time LE2 called the signalman and advised him that his train was ready to depart. The signalman set the route for Train 951 to depart from the south end of Middleton yard, enter the up main line and cross over to the down main line (refer Figure 1). He called the train controller for permission to dispatch the train and once this had been received he cleared Signal 202 (refer 1.2.3) for Train 951 to depart. Section 7 of the Working Timetable Instruction 7.8 Middleton Shunting Yard, clause 7.8.1 Trains Arriving and Departing - General Instructions, stated in part that:

> Trains/shunting services enter Middleton Yard as directed by the Service Co-ordinator...
>
> **Authority to Depart -** When the yard is attended the Service Co-ordinator must advise the Signalman when a train/shunting service is ready to depart. When unattended the Locomotive Engineer of the train/shunting service concerned will call the Signalman.
>
> **Berthing Arrangements -** The low speed signal authorising a train/shunting service to enter the yard should not be illuminated unless the Signalman has permission from the Service Co-ordinator/Rail Operator . . .

The signalman had not received advice from the service co-ordinator that Train 951 was ready to depart.

1.1.10 LE2 said that he could not initially see Signal 202 from where his locomotive was standing because the signal was obscured by a floodlight tower so he moved his train cautiously forward until he could see the signal. From there he saw the "clear proceed" (green) indication on Signal 202 which told him that the route was correctly set for the departure of his train and that he was authorised to proceed. At that time he was unaware that Train 828 was approaching Signal 212 up home signal at Middleton.

1.1.11 After passing Signal 202 LE2 could see the headlight of Train 828 approaching. He commented to the shunter that the headlight of the approaching train was on full beam and he flashed the headlight of his locomotive to full beam briefly to remind LE1 that his headlight was on full beam. It was usual for LEs to dip their locomotive headlights when approaching other trains. The headlight of Train 828 remained on full beam.

1.1.12 Because of the bright light LE2 could not determine if Train 828 was moving or not but assumed it had stopped at Signal 212 with the headlight on full beam, while waiting for his train to clear Middleton. As the locomotive of Train 951 moved from the Middleton yard and entered the up main line, LE2 realised that the approaching train had passed Signal 212 and was about to collide with his train.

1.1.13 He made an emergency brake application and called a warning to the shunter before he got down on the floor to protect himself from the impact.

1.1.14 The point of impact was between 207 points and 206 points, about 125 m past Signal 212 (refer Figure 2).

1.1.15 Train 951 was travelling at 22 km/h at impact and Train 828 was travelling at 36 km/h.

1.1.16 The 3 train crew suffered minor injuries as a result of the collision.

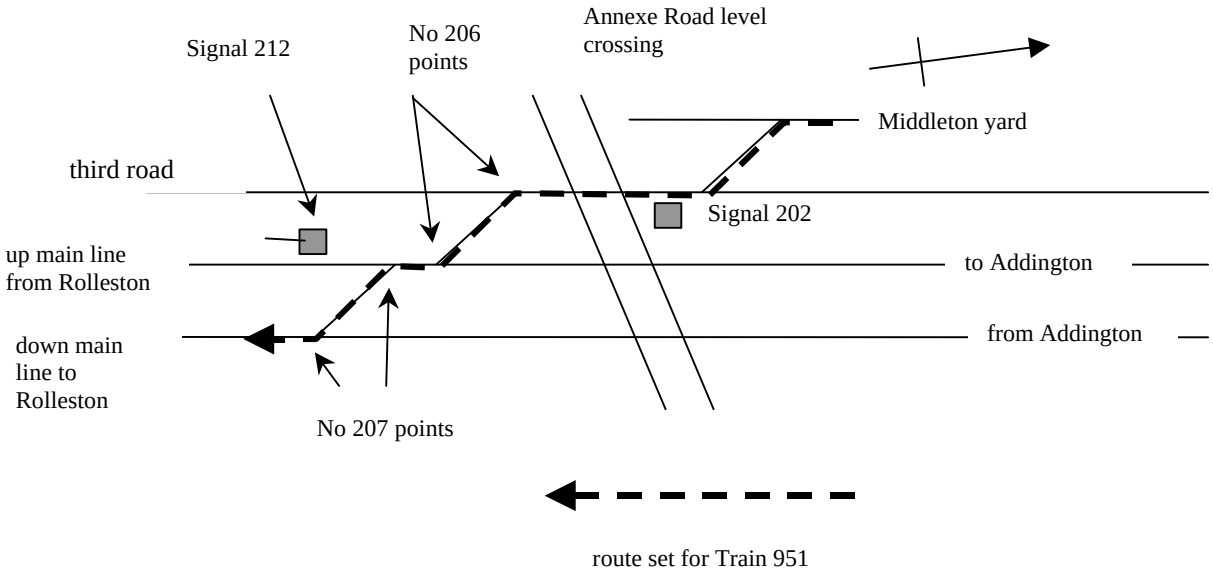

Figure 1
Route for Train 951 departing Middleton
(not to scale)

1.2 Site details and signalling arrangements

1.2.1 The line from Middleton south to Islington, about 7.5 km, was double track and operated under double line automatic signalling rules and regulations.

1.2.2 Signalling for the Middleton yard and surrounding area was controlled from the Addington signalbox. Before berthing trains in the Middleton yard the signalman was required to get permission from the Middleton operations office. This office usually also advised him when trains were ready to depart from the yard, although it was not uncommon for the LE of a train to call when the brake test had been completed and his train was ready to depart.

1.2.3 Signal 202 was a ground signal (refer Figure 3) which authorised the departure of trains from the south end of Middleton and was controlled by the signalman at Addington signalbox. A "clear proceed" (green) indication could only be obtained on Signal 202 after points 206 and 207 had been reversed and the route was correctly set for a departing train to cross to the down main line.

1.2.4 Signal 212 was a stop-and-stay up home signal at Middleton (refer Figure 4). It was controlled by the signalman at Addington signalbox. Once the signalman had obtained permission to berth a train he then set the necessary route and illuminated the low speed light on Signal 212 to authorise the train to enter the Middleton yard.

1.2.5 Tranz Rail's Rule 56(b)(iv) described low speed lights as:

> . . . lights which display a short range Yellow light when at "Proceed" but normally do not show any light.

1.2.6 Tranz Rail's Rule 57(a)(i) defined the speed indicated by a low speed signal as:

> Low speed. Displayed by a low speed light below two Red lights. Indicates that the points are in the proper position but not necessarily that the track is unoccupied. Locomotive Engineer must proceed cautiously at such speed (not exceeding 25 km/h) as will enable him to stop clear of any obstruction.

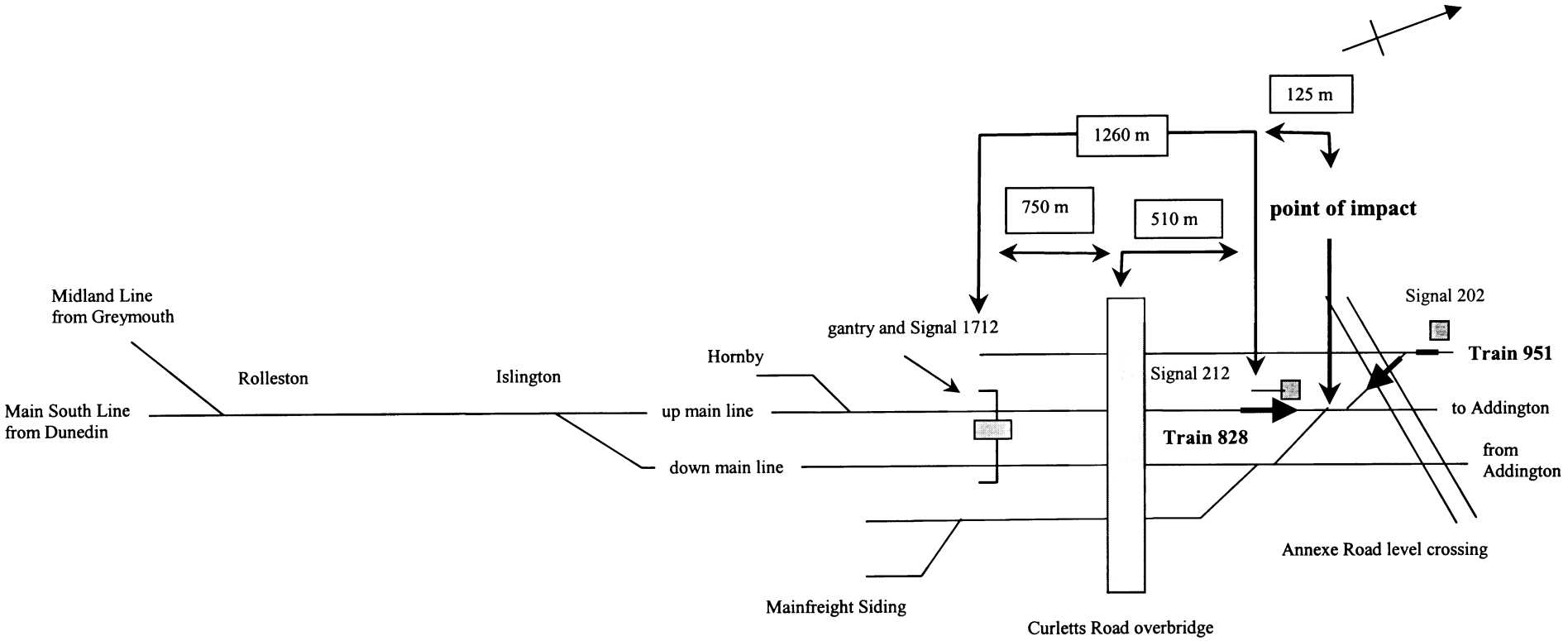

Figure 2
Track plan from Signal 1712 to Middleton
(not to scale)

Figure 3
Signal 202 with Points 206 and 207 and Curletts Road overbridge in the background

Figure 4
Signal 212 (Up main home signal)

1.2.7 Signal 1712 was a gantry-mounted stop-and-stay intermediate signal positioned about 1260 m in advance of Signal 212, which acted as a warning to the LE of a train approaching Middleton on the up main line of the indication being displayed by Signal 212. When Signal 212 displayed a "Stop" (red) indication Signal 1712 displayed a "caution proceed" (yellow) indication. If Signal 212 was displaying a low speed indication, as for a train to enter the Middleton yard, Signal 1712 still displayed a "caution normal speed" indication. The only time Signal 212 displayed a "clear proceed" indication was when the route was set for a train to bypass Middleton on the up main line with Signal 212 at "clear proceed" (green).

1.3 Locomotive event recorder data

1.3.1 The event recorder data from the locomotives of both trains was downloaded and supplied for analysis.

1.4 The locomotive vigilance device

1.4.1 The vigilance device went through a cycle of a light illuminating every 50 seconds if no locomotive controls were moved. If there was no response to the light within 10 seconds, a buzzer sounded in the cab. If there was no response to the buzzer in the next 10 seconds, braking was automatically applied and an alarm sounded in train control. The LE could reset the vigilance device at any time by either manually pushing the button or operating the controls of the locomotive.

1.4.2 The most appropriate form of vigilance device had been considered previously by Tranz Rail. Page 52 of the 1997 Tranz Rail Alertness Management booklet included:

> "Four forms of vigilance device are to be assessed as follows:
>
> 1. Fixed time cycles (as used at present)
> 2. Random time cycle to vigilance light
> 3. Speed dependent time to vigilance light
> 4. Fixed time cycle, but with randomly selected vigilance light with associated cancellation button"

and referred to other options to form part of a final assessment. Tranz Rail advised no changes had been made to the fixed time cycle system in use in 1997 as a result of this assessment and supplied the following update indicating its intention to re-activate the project:

> The enhanced vigilance system known as "Kaitiaki" has been progressively fitted to mainline class locomotives since 1993.
>
> Vigilance systems have been configured to the same cycles as the previous system, but are capable of being adapted to the different cycles outlined in the Alertness Management booklet.
>
> The randomly selected vigilance light was the first to be considered. It was fitted to a locomotive based in Wellington for evaluation by Locomotive Engineers. This system was subsequently withdrawn following feedback it had too much potential to distract Locomotive Engineers from their primary task of handling their train in accordance with visual information provided by signals, curve speed boards, speed restriction boards etc.
>
> The other two versions were fitted to six locomotives during 1997 for evaluation. There was some variable feedback, however the project team involved did not reach any specific conclusion.
>
> It is planned to re-activate the project within the recently formed Locomotive Engineers Council, which includes Tranz Rail and RMTU members.

1.5 Personnel

LE of Train 828 (LE1)

1.5.1 LE1 had 27 years' experience, of which 18 were as a Grade 1 LE. Most of his service had been as a Grade 1 LE in Christchurch. He held a current operating certificate for his duties.

1.5.2 LE1's last theory examination for recertification was on 27 November 2000.

1.5.3 He was in good health and did not consider he was suffering from any home or work related stress.

1.5.4 In the 11 days before the incident LE1's rostered hours on his mini roster[2] were 86 hours 39 minutes which excluded a day off by request at the beginning of the fortnight. The mini rostered and corresponding actual hours worked by LE1 prior to the incident are shown in the following table.

		Rostered hours	Actual hours
Day 1	Off by request		
Day 2	1300 - 1700	4 hours	4 hours
Day 3	0820 - 1900	10 hours 40 minutes	11 hours 20 minutes
Day 4	0935 - 1745	8 hours 10 minutes	8 hours 10 minutes
Day 5	0935 - 1745	8 hours 10 minutes	9 hours 5 minutes
Day 6	1035 - 1925	8 hours 50 minutes	8 hours 50 minutes
Day 7	1730 - 2359	6 hours 29 minutes	7 hours 15 minutes
Day 8	2040 - 0500	8 hours 20 minutes	8 hours 20 minutes
Day 9	2115 - 0650	9 hours 35 minutes	9 hours 45 minutes
Day 10	2135 - 0545	8 hours 10 minutes	9 hours 10 minutes
Day 11	2135 - 0545	8 hours 10 minutes	9 hours 25 minutes
Day 12	2150 - 0355	6 hours 5 minutes	6 hours 10 minutes
Total		**86 hours 39 minutes**	**91 hours 30 minutes**
Day 13	2040 - 0500	8 hours 20 minutes	
Day 14	2345 - 0855	9 hours 10 minutes	

Day 2 had been a rostered day off for LE1 but he had gone to work for his theory recertification.

Days 7 (Saturday 2 December) and 8 (Sunday 3 December) were also rostered days off but LE1 said that he worked these in response to requests from the roster centre to fill vacant jobs because of a shortage of LEs.

The incident happened at the end of the shift on Friday 8 December.

1.5.5 LE1's shift on Day 12 was his 11th consecutive shift for the fortnight and he was rostered for night shifts on Day 13 and Day 14 following the collision. Assuming LE1 had worked his fortnight without incident he would have worked 13 consecutive shifts in the fortnight, 7 of which would have been night shifts, for a total of about 108 hours. He had already worked 91 hours 30 minutes for the fortnight at the time of the collision. His rostered hours from his Mini Roster for the fortnight were 104.

1.5.6 LE1 said that he had been through a 30-minute Tranz Rail Alertness Management Programme "about 3 years ago".

[2] The Mini Roster was the actual roster the LE was required to work to, compiled from the agreed base roster but amended some weeks before commencement to allow for staff unavailability and for train cancellations.

1.5.7 In 1999 LE1 had attended a sleep clinic and had been successfully treated for positional obstructive sleep apnoea[3], which had previously caused some sleep disturbance and sleepiness while on duty.

1.5.8 The sleep and wakefulness studies were repeated in January 2001, following the collision, and it was confirmed that a complete resolution of the adverse effects of obstructive sleep apnoea had been achieved since 1999. While LE1 did report some daytime sleepiness while working since that time, all reports of sleep quality were normal, and these symptoms were not ascribed to obstructive sleep apnoea.

1.5.9 LE1 said his sleep habits when working night shift were that he usually tried to "get about 6 or 7 hours after the shift, have an early tea and go to bed for 2 or 3 hours, and then get up and go to work". He said that his house was double glazed to help with his sleeping, and his family understood his sleep habits and requirements.

1.5.10 LE1 said that a number of LEs who spoke to him after the collision commented that they had fallen asleep in the cab for short periods several times. Another LE interviewed by the commission said that he believed that LEs experiencing microsleeps were widespread throughout the Tranz Rail system.

LE of Train 951 (LE2)

1.5.11 LE2 had 16 years' experience and was a Grade 1 LE. He held a current certification for the duties he was performing.

1.5.12 His shift on Friday 8 December had commenced at 0035 and he was doing his first shift since returning from 18 days' annual leave.

1.6 Rostering

1.6.1 Tranz Rail had procedures in place for controlling base hours of work, including maximum shift lengths, shift rotation and time between shifts. Section 3, Clause 1.0 of the Tranz Rail "Rail Operating Manual" specified that rosters were to be constructed at or about 80 hours each fortnight - within 76 to 83 hours being considered acceptable. There was no separate control on the maximum mini rostered or actual hours worked over a fortnight.

1.6.2 Figure 5 shows the work patterns for LE1 for 4 weeks preceding the collision. The shaded bars indicate the rostered times of his shifts (from his mini roster sheets), while the associated lines indicate the times he actually worked (from his corresponding timesheets). Work periods with no corresponding rostered times were all extra shifts.

[3] Obstructive sleep apnoea is a medical condition where intermittent obstruction of the upper airways during sleep leads to repeated sleep disturbance and excessive daytime sleepiness.

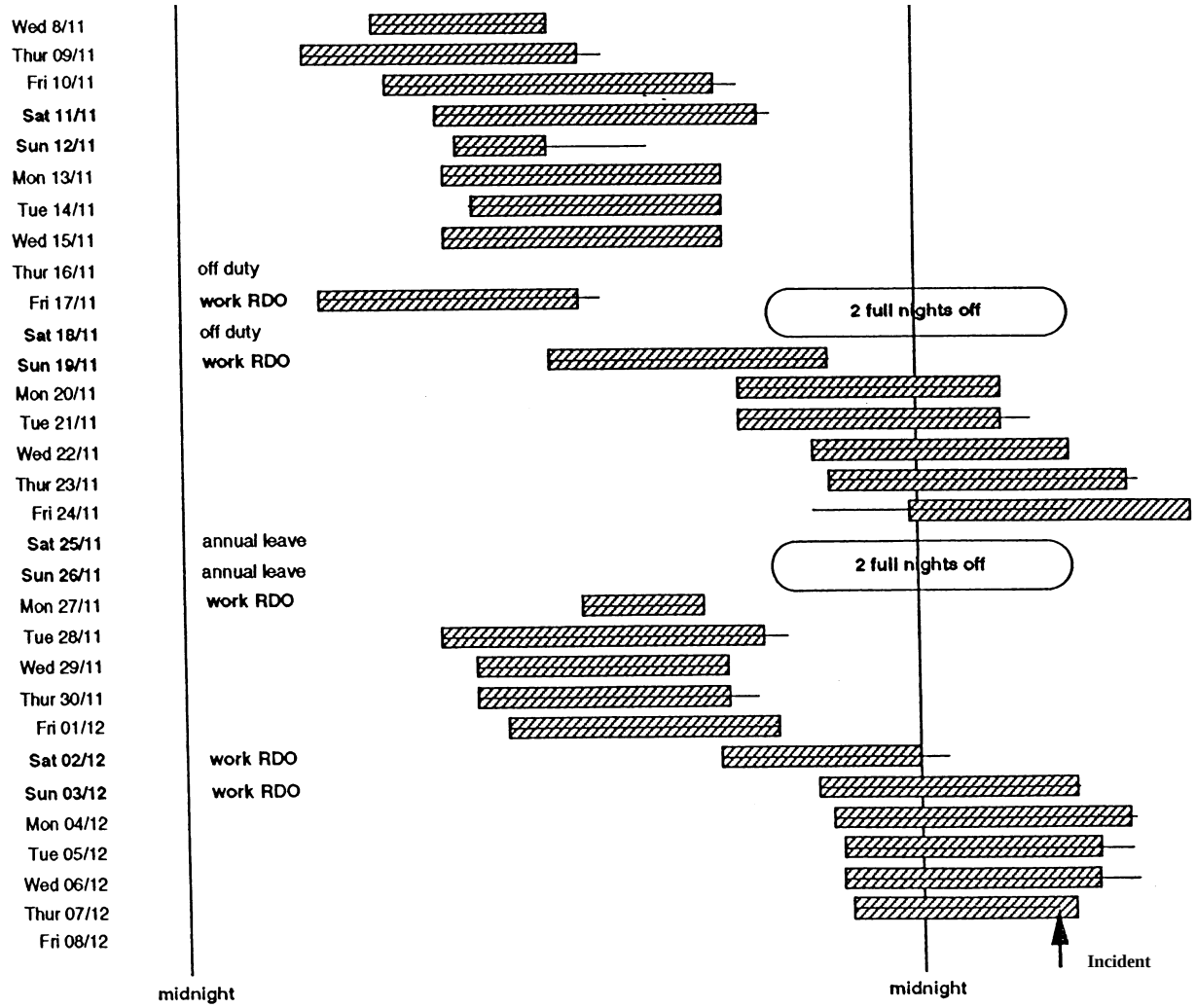

Figure 5
Work patterns for LE1 over the 4 weeks prior to the collision

1.7 Fatigue

1.7.1 LE1 reported "a bit of a blank until I woke up underneath the Curletts Road overbridge", which prompted a close look at the possible role of accrued sleep debt and fatigue in this incident. The Commission engaged Associate Professor Philippa Gander PhD, an internationally recognised sleep and fatigue management expert, to assist in this area. Her input is included in sections 2.5, 2.6 and 2.7.

1.8 Previous occurrences involving attention loss

1.8.1 The Commission has investigated 2 other recent occurrences involving reported microsleeps with a possible link to sleep loss and fatigue. They are:

- Railway Occurrence Report 00-115, Westmere, a derailment on 22 September 2000, following a high speed entry into a restricted speed curve
- Railway Occurrence Report 00-117, Kai Iwi, a derailment on 26 November 2000, also following a high speed entry into a restricted speed curve.

In addition Report 00-111, Tapuata, involving a track warrant overrun on 14 June 2000, concluded a short-term loss of attention may have been a factor in the events that occurred, although sleep loss and fatigue were not considered to be factors (published April 2001).

2. Analysis

2.1 Actions of the signalman, LE2 and the train controller

2.1.1 Prior to the departure of Train 951 the signalman followed correct procedures; however advice that the train was ready to depart should have come from the service co-ordinator and not directly from LE2, although it had become a common practice for LEs to contact the signalman direct when their trains were ready to depart.

2.1.2 The actions of LE2 prior to and as Train 951 departed Middleton were appropriate although he should not have advised the signalman direct that his train was ready to depart. However, this did not contribute in any way to the collision.

2.1.3 The actions of the train controller were appropriate in advising the signalman of the approach of Train 828.

2.2 Locomotive event recorder data

2.2.1 Analysis of the event recorder output for Train 951 showed that LE2 made an emergency brake application about 2 seconds before impact.

2.2.2 The time sequence of events as derived from the locomotive event recorder for Train 828 is shown in Figure 6.

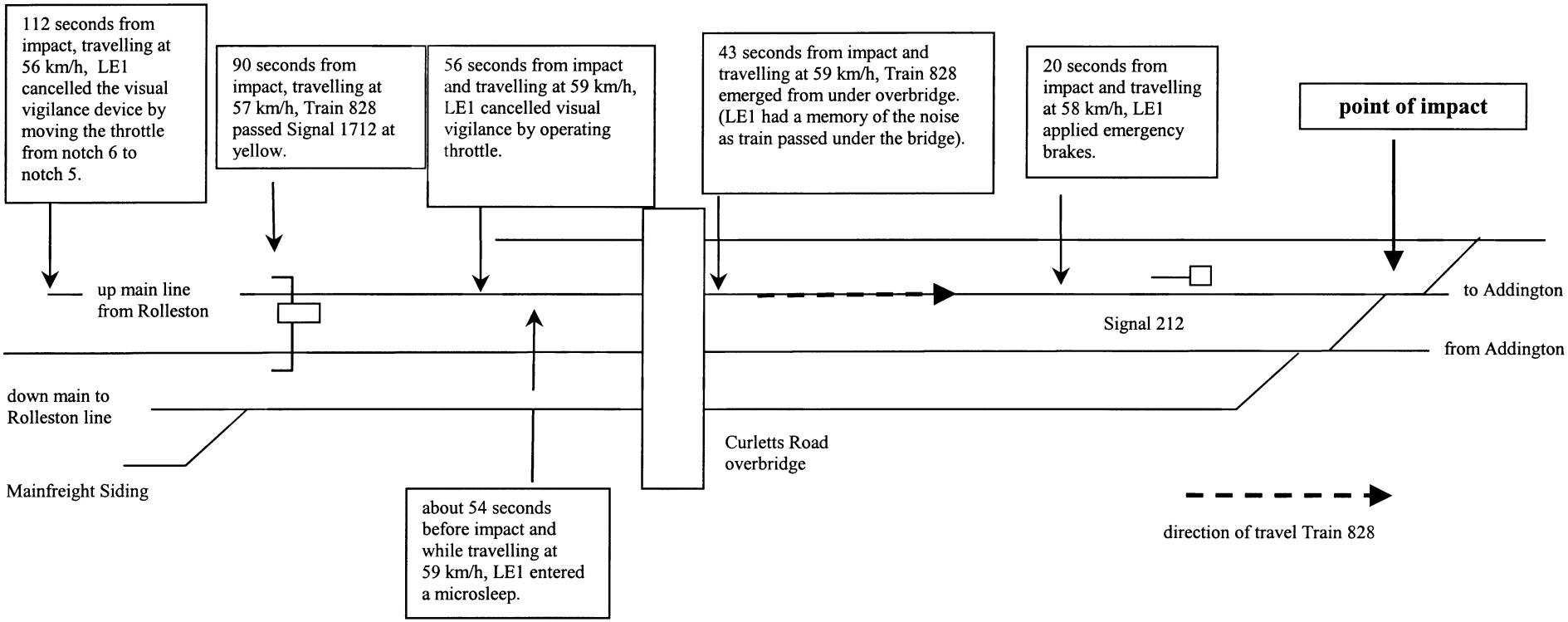

Figure 6
Time sequence of events
(not to scale)

2.2.3 The speed of Train 828 was 56 km/h and the throttle was in notch 5 when LE1 cancelled a vigilance alert about 112 seconds before impact.

2.2.4 About 90 seconds before impact the train passed Signal 1712, 1260 m before Signal 212, at 57 km/h. The throttle was in notch 5.

2.2.5 About 56 seconds before impact and 13 seconds before passing under Curletts Road overbridge LE1 cancelled another vigilance alert by notching the throttle back from notch 5, where it had been for the previous 54 seconds, to idle.

2.2.6 Train 828 passed under Curletts Road overbridge, 510 m from Signal 212 and 43 seconds before impact at 59 km/h with the throttle still in the idle position.

2.2.7 About 20 seconds and 280 m from the point of impact LE1 made an emergency brake application. At this point Train 828 was travelling at 58 km/h.

2.2.8 The locomotive event recorder confirmed that the vigilance alarm had operated 4 times during the 6 minutes leading up to the collision and the response time by LE1 varied between 5 and 12 seconds, which was within the expected response range.

2.3 Actions of LE1

2.3.1 LE1's recollections of his return journey from Cass confirmed that he was awake as his train joined the Main South Line at Rolleston and travelled towards Middleton. He remembered approaching Signal 1712 and seeing the "caution proceed" (yellow) indication it displayed. He remained awake for at least another 30 seconds as he cancelled a vigilance alarm by operating the throttle before he succumbed to a microsleep. It is highly likely that LE1 was close to asleep at the time of operating the throttle to cancel the vigilance alarm, and that his action was a deliberate move to shut off power knowing that the next signal was displaying either a low speed or stop indication.

2.3.2 The sound of Train 828 going under Curletts Road overbridge probably aroused LE1 to semi-consciousness but he probably was not fully awake and did not regain situational awareness for some time after that.

2.4 Vigilance device

2.4.1 LE1 had cancelled the vigilance alarm 56 seconds before impact, which would have automatically restarted the vigilance cycle. If the LE had not awakened after going under Curletts Road overbridge, the illuminated cycle of the device was unlikely to have awoken him, and it would have been another 10 seconds before the alarm became an audible one. If Train 951 had not been in Train 828's path and the route had been set for Train 828 to enter Middleton yard, it would have done so at a speed of about 58 km/h, which was about 33 km/h faster than the authorised maximum entry speed of 25 km/h under a low speed signal indication.

2.4.2 This scenario could have resulted in a serious and potentially life-threatening situation. The vigilance device was not able to prevent this accident, nor would it have necessarily prevented this alternative scenario, which raises a doubt over its suitability in its present form as a defence against short-duration microsleeps.

2.5 LE fatigue

Method for assessing fatigue

2.5.1 Fatigue assessment was based on a method developed by the US National Transportation Safety Board and the NASA Fatigue Countermeasures Program [(1)]. Bracketed number references used in the assessment are included at Appendix 1.

The method seeks information on the following factors known to produce fatigue-related performance impairment:

- extended wakefulness
- acute sleep loss and cumulative sleep debt
- presence of a sleep disorder
- critical times in the daily cycle of the circadian body clock.

Sleep history

2.5.2 LE1 was an experienced shift worker who had developed a pattern of sleep for coping with night shifts. He described his usual daytime sleep as 6 to 7 hours in the morning and 2 to 3 hours in the evening prior to going back to work. This "split sleep" pattern is common among night workers [(2,9)] and there is considerable scientific evidence to indicate that the sleep period prior to night duty is very effective in improving alertness and performance across the night shift.

2.6 Factors that increase the likelihood of falling asleep uncontrollably

Time of day

2.6.1 Biological sleepiness[4] waxes and wanes across the daily cycle of the circadian body clock. There is clear evidence, from laboratory studies, that people are most prone to falling asleep inadvertently in the early hours of the morning and again in mid-afternoon [(1-6)]. This has been confirmed in studies of locomotive engineers.

2.6.2 A German study suggests that locomotive engineers' vigilance is at its worst in the early hours of the morning [(8)]. Automatic brakings (caused when locomotive engineers failed to push an alertness device while passing a pre-signal set in the warning position) were most likely to occur at around 0300 and again in the early afternoon. A similar pattern was found for the warning hooter that sounded when the locomotive engineers failed to respond to a warning light that switched on every 25 seconds, as a vigilance device. The warning hooter was most likely to sound around 0300 and again in the early afternoon.

2.6.3 The collision occurred at about 0400, which corresponds to time in the daily cycle of the circadian body clock when the biological urge to fall asleep is at its strongest.

[4] Biological sleepiness is effectively a message from the brain that it requires sleep, similar to hunger indicating need for food or thirst indicating a need for water. Biological sleepiness eventually becomes overwhelming, leading to falling asleep uncontrollably.

Time on shift

2.6.4 The German study also found that how long a locomotive engineer had been on shift affected how impaired his alertness became in the early hours of the morning [8]. The 0300 peak in soundings of the warning hooter (owing to missing the visual warning on the vigilance device) was much more marked among locomotive engineers who were in the 4th to 6th hour of their shift at the time, than among locomotive engineers who were in the first 3 hours of their shift.

2.6.5 At the time of the collision LE1 had been on shift for about 6 hours and this would have contributed to his decreased alertness and increased biological sleepiness.

Duration of continuous wakefulness

2.6.6 Laboratory studies consistently show that biological sleepiness increases the longer a person stays awake. However, LE1 indicated that there was nothing unusual about his sleep prior to the shift on which the collision occurred.

2.6.7 Assuming that LE1 had followed his usual sleep pattern and had a nap prior to commencing his shift, he would not have been awake for an extended period of time when the collision occurred and extended wakefulness would not have contributed to his biological sleepiness at the time of the collision.

Prior sleep loss

2.6.8 Insufficient prior sleep increases biological sleepiness at all times in the circadian body clock cycle. To be alert and to function well, each person requires a specific amount of nightly sleep. If individual "sleep need" is not met , the consequences are increased biological sleepiness, reduced alertness and impaired physical and mental performance [3,5,10].

2.6.9 For most people, getting 2 hours' less sleep than they need on one night (an acute sleep loss of 2 hours) is enough to consistently impair their performance and alertness the next day. The reduction in performance is particularly marked if less than about 5 hours' sleep is obtained [11,12]. The effects of several nights of reduced sleep accumulate into a "sleep debt", with sleepiness and performance becoming progressively worse [10,13]. It typically takes 2 full nights for sleep and daytime functioning to return to normal after sleep loss [11,13,14].

2.6.10 In general, night workers find it difficult to obtain extended sleep during the day [2,6-9]. Typically, daytime sleep periods are about a third shorter than night-time sleep periods [2,9]. The more rapid accumulation of sleep debt on night shift is recognised in regulations in other transportation sectors that limit the number of night shifts in a row. For example, air traffic controllers are generally limited to 2 night shifts in a row [16].

2.6.11 The shift on which the collision occurred was the 11th consecutive shift worked by LE1 and the 6th consecutive night shift. On the preceding weekend he had worked both of his rostered days off and both of these extra shifts involved night work. Based on his preceding work pattern (and in the absence of a detailed sleep history), it seems highly likely that LE1 was experiencing the effects of a cumulative sleep debt at the time of the collision.

Presence of a sleep disorder

2.6.12 The restorative value of sleep, in terms of reducing biological sleepiness and improving subsequent waking function, depends not only on the amount of sleep obtained but also on its quality. Sleep that is restless and fragmented by frequent awakenings also leaves a person sleepy and at increased risk of impaired alertness and performance [10]. There are a large number of recognised disorders that can disrupt the quality of sleep [17].

2.6.13 The effect of a past history of obstructive sleep apnoea was evaluated as to whether it was a potential cause of the involuntary sleep onset in this collision. Recent sleep and alertness studies conducted while LE1 was not working had identified no abnormal tendency to fall asleep when normally awake and shown normal breathing during sleep. It is therefore unlikely that obstructive sleep apnoea was present to any significant degree in the sleep prior to the collision, and that the excessive tendency to sleep was wholly explicable by the rostered arrangements for work and rest.

2.7 Rostering issues

Forward rotation and short breaks between shifts

2.7.1 The overall pattern of LE1's rostered shifts indicated that rotation was primarily forward, that is consecutive shifts occurred progressively later. This is generally considered to be preferable to backwards rotation, because the circadian body clock has a tendency to run slightly slow, and it is easier to fall asleep later, rather than earlier [9,18,19]. Forward rotations also reduced the likelihood of very short breaks between shifts, which can restrict the time available for sleep, because each new shift starts later than the preceding one.

2.7.2 Breaks between shifts must also contain all the other activities of life, including commuting to work, eating, interactions with family and friends, exercise and other recreation etc, and where there is insufficient time available for these activities there could be pressure on LEs to cut back their sleep time.

2.7.3 The amount of sleep that a person can obtain during a break is highly dependent on the time of day at which the break occurs [18]. Short breaks between shifts, particularly during the day, limit the time available for sleep and can accelerate the accumulation of sleep debt across consecutive shifts.

Late running

2.7.4 Late running, particularly after night shifts, reduces the time available for sleep and can contribute to the accumulation of sleep debt across consecutive shifts.

2.7.5 On the 2 nights preceding the collision LE1's shifts had been of extended duration because of late running. His shift starting on Tuesday 5 December 2000 had finished one hour late while his shift starting on Wednesday 6 December 2000 had finished one hour 15 minutes late. Night workers are seldom able to sleep beyond the early afternoon, when the circadian body clock moves the brain and body into "awake mode" and sleep becomes difficult, if not impossible [9]. These late-running shifts significantly restricted LE1's opportunity to sleep during the biologically preferred time, and may well have increased his sleep debt at the time of the collision.

2.7.6 Of the 10 consecutive shifts worked by LE1 prior to the collision, 5 had run at least 40 minutes late, which meant that LE1 had worked a total of 4 hours 46 minutes longer than was rostered.

Working on rostered days off

2.7.7 In the 4 weeks preceding the collision (starting Thursday 9 November), LE1 had worked on 5 of his 7 rostered days off. This resulted in his being on his 11th consecutive shift on the night of the collision. Similarly, because he had worked his rostered day off on 23 October, he had worked 13 consecutive shifts between Wednesday 18 October and Monday 30 October.

2.7.8 There can be numerous reasons why LEs agree to work extra shifts over and above those for which they are originally rostered. These include:

- remunerative incentives
- loyalty to fellow LEs at the depot, who may be less well rested or have important commitments away from work
- concern about possible effects of refusal on relationships with other LEs, or with the company
- professional motivation to ensure that the system runs smoothly
- loyalty to the company.

2.7.9 Call outs at the Middleton locomotive depot were common for crewing extra trains or to relieve crews of late-running trains and it seems reasonable to conclude that LE1's willingness to work additional shifts was primarily in response to the company's needs rather than personal factors.

2.7.10 In the month preceding the collision LE1 had twice been rostered on a block of 5 consecutive night shifts and on both occasions he had agreed to work on a rostered day off immediately prior to starting the block of night shifts.

2.7.11 Working additional shifts reduces the time available for all other activities away from work, including opportunities for recovery sleep. More limited off-duty time may further increase the pressure to sacrifice sleep to meet other time demands such as household and family roles, or recreational activities.

2.7.12 Working additional shifts prior to a block of night shifts prevents an LE from being well rested going into the night shifts.

Opportunities for recovery from sleep debt

2.7.13 For daytime functioning to return to normal after sleep loss it typically takes 2 full nights of sleep [11,13,14]. In the month preceding the collision LE1 had only one break of at least 48 hours free from work, from 0500 on Saturday 25 November until 1300 on Monday 27 November. He was rostered off duty for one 4-day block from 16 November to 19 November but worked on the 17th and 19th. He was also rostered off duty for one 2-day block on 2 and 3 December, but worked on both of these days.

2.7.14 During this period, the timing of his day shifts suggests that he would generally have been able to obtain adequate sleep while working days but the shifts he worked on rostered days off prior to his blocks of night shifts meant that he probably began each block of night shifts already in sleep debt.

Conclusions

2.7.15 If ignored, biological sleepiness will eventually build to a level where it is overwhelming. Comments from LEs indicated that LEs losing awareness and experiencing microsleeps while driving was not uncommon.

2.8 Comparison of the 3 recent incidents in which microsleeps were suspected

Work-related features

2.8.1 The data included in this section is a repeat of that included in Railway Occurrence Report 00-117, which related to a derailment on 26 November 2000 and is relevant to this incident.

The following table compares 3 recent incidences (see paragraph 1.10.1 of Railway Occurrence Report 00-117) involving suspected microsleeps:

	Westmere Derailment (00-115) 22/9/2000	**Kai Iwi Derailment (00-118) 26/11/2000**	**Middleton Collision (00-121) 8/12/2000**
Time of day	2338	0105	0400
Time on shift	4 hrs	3 hrs 25 mins	6 hrs
Consecutive night shifts	5th	5th	6th
Completed shifts since last 2-night break	4	4	10
Late running on prior night shifts	4/4 (average 1.6 hrs)	4/4 (average 1.4 hrs)	4/5 (average 38 mins)*

* The 2 night shifts preceding the incident had run an average of 1.2 hrs late.

These incidents have in common that they occurred at least 3 hours into a night shift that was the 5-6th in a sequence of nights. The preceding night shift had also run late. They all occurred at or near the daily peak in biological sleepiness. None of the drivers perceived that the events leading up to the incident (either at home or at work) were in any way unusual.

In all 3 cases microsleeps prevented LEs from taking actions necessary to maintain the safety of their train. In both the Westmere and Kai Iwi derailments the LEs fell asleep near the top of an ascending grade, and then did not brake in time to reduce speed as they headed into a series of curves on the down grade. In the Middleton collision, the LE probably fell asleep after passing a yellow signal, waking as he approached the next signal at red, but too late to stop his train from colliding with an oncoming train."

3. Findings

3.1 Train 828 collided with Train 951 as a result of passing Signal 212, which was displaying a "Stop" (red) indication.

3.2 The passing of the signal resulted from LE1's loss of attention and situational awareness consistent with his having fallen asleep.

3.3 LE1 was probably experiencing the effect of an accumulated sleep debt at the commencement of his shift on Thursday 7 December 2000.

3.4 The collision occurred at a time when LE1's biological sleepiness would be expected to be increasing rapidly towards its daily maximum.

3.5 LE1's increase in sleepiness owing to the daily cycle of his body clock would have been exacerbated by his prior sleep loss, and by his being 6 hours into the shift.

3.6 LE1's past history of obstructive sleep apnoea was not a contributing factor to his microsleep.

3.7 The willingness of LE1 to work extra shifts when called on may have made him a popular "call out" choice and ultimately contributed to the excessive hours he had worked.

3.8 The existing locomotive vigilance system may not provide an effective defence against microsleeps and the possibility of similar occurrences.

3.9 Tranz Rail had no monitoring system to control total mini-rostered and actual hours worked each fortnight.

3.10 The mini-rostered hours for LE1 for the fortnight 26 November to 9 December (104 hr 9 min) were excessive.

3.11 The actual fortnightly hours (about 109) which would have been worked had the incident not occurred were excessive.

3.12 LE1 was appropriately certified for his duties.

3.13 The actions of the signalman, LE2 and the train controller did not contribute to the collision.

4. Safety Actions

4.1 On 17 April 2001 Tranz Rail advised that:

4.1.1 Following investigations into a sleep related derailment at Westmere on 22 September 2000, Crew Controllers had been instructed to err on the side of safety and call a Locomotive Engineer for an additional shift if recommended shift rotations would be disturbed. On this occasion the shift rotations were not an issue, however the number of consecutive shifts may have contributed on this occasion. A new report has therefore been developed showing sequence of fortnightly hours worked by Locomotive Engineers. This is designed to detect and manage those staff frequently working long hours.

A proposal has been forwarded to RMTU (the union representing Locomotive Engineers employed by Tranz Rail) regarding the introduction of mandatory days off duty to ensure Locomotive Engineers restore accumulated "sleep debt". This is now to be included in a review of all rostering practices for Locomotive Engineers, to be undertaken by the Locomotive Engineers Council (a joint Tranz Rail/RMTU forum).

The Crew Management System has been changed to identify the number of consecutive hours/shifts worked by Locomotive Engineers. This change took effect in mid February 2001.

The Alertness Management Program is presently being updated and is expected to be available for review by mid June 2001. Once completed, all Locomotive Engineers will be trained or re-trained. The Safety Observation database will be used to measure completion of training.

In the interim, key elements of the present Alertness Management Program have been included in weekly safety notices.

The number of Locomotive Engineer training courses for 2001 has been increased from three to five.

The Locomotive Engineer has been referred to the Sleep Investigation Centre at Bowen Hospital, Wellington, for examination.

4.1.2 As an update on the safety actions included in 4.1.1, Tranz Rail advised on 5 June 2001:

Clause 1
The specification for this report was finalised on 14 October 2000. The report was implemented on 27 November 2000.

Clause 2
The Locomotive Engineers' Council has held initial discussions on potential changes to rostering parameters during its 10/11 May 2001 meeting. More discussions are to take place at the 6/7 June 2001 meeting. This will include a more detailed review of the application of suggested changes to actual rosters. It is likely some work will need to be done beyond this meeting.

Clause 3
The actual date of the change was Sunday 18 February 2001.

Clause 4
The consultants Tranz Rail have engaged for this work have now indicated a draft will be available for review by the end of July 2001.

Clause 5
The key summary points for Alertness Management strategies have been circulated in the Weekly Safety report. This commenced on 12 January 2001 and was completed on 2 March 2001.

Clause 6
Three courses have been completed or are presently in progress. The candidates from all of these courses are presently undergoing On the Job Training.

Two further courses are planned to commence during July and September 2001.

Clause 7
The Locomotive Engineer has been assessed at the Sleep Investigation Centre.

4.2 Tranz Rail advised it intends to commission Associate Professsor Philippa Gander, PhD, Director, Sleep/Wake Research Centre, to update the present training package for LEs before the end of 2001. This will be followed by any further revision, and when complete, training of trainers. In the interim, information from the existing package has been highlighted in weekly safety information sent to operating staff, including LEs.

4.3 Tranz Rail subsequently advised that as a result of recent incidents it had:

since reviewed recent literature relating to shift work and has found present day opinion suggests night shifts should be limited to a sequence of two to three shifts.

This concept has been reviewed by the Locomotive Engineers' Council (a joint Tranz Rail/RMTU forum) and steps have been taken to prepare and trial rosters structured in this manner in three depots. The trial will include surveying Locomotive Engineers to establish if they find the lesser exposure to accumulation of sleep debt reduces their level of fatigue.

5. Safety Recommendations

5.1 The following safety recommendations to the managing director of Tranz Rail relating to control of hours of work, Alertness Management training and the operation of vigilance devices were included in Railway Occurrence Report 00-115 regarding a derailment at Westmere on 22 September 2000:

5.1.1 put in place control measures to ensure:

- Mini Rosters are controlled within defined criteria compatible with the principles used in compiling base rosters
- defined criteria are met before offering extra shifts to LEs
- actual hours are monitored and immediate corrective action taken when late running or other factors increase rostered shifts to defined unacceptable levels (017/01)

5.1.2 implement Alertness Management courses to reach at least 90% of LEs by the end of 2001 and 100% by the end of 2002 (018/01)

5.1.3 revise the operation of the vigilance device system to provide a better defence against short duration microsleeps (019/01)

5.2 The following safety recommendation to the managing director of Tranz Rail relating to biological sleepiness leading to microsleeps was included in Railway Occurrence Report 00-117 regarding a derailment near Kai Iwi on 26 November 2000:

5.2.1 research information available on factors contributing to biological sleepiness in LEs, with particular regard to the possible adverse effect of continuous night shifts, and take steps to:

- minimise the probability of biological sleepiness leading to microsleeps
- provide an effective defence against any microsleep which may occur leading to an unacceptable risk exposure. (025/01)

5.2.2 These safety recommendations are equally applicable to this incident.

Approved for publication 11 July 2001

Hon. W P Jeffries
Chief Commissioner

Appendix 1

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