Report 00-117

express freight Train 540

derailment

near Kai Iwi

26 November 2000

Abstract

On Sunday, 26 November 2000 at about 0105, Train 540, the northbound Longburn to Whareroa milk train, derailed near Kai Iwi while rounding a curve about 25 km/h faster than the authorised and posted curve speed of 50 km/h. Ten full milk-tanker wagons left the track and came to rest in a gully below, disgorging a large volume of milk. There were no injuries.

The reason for the excessive speed in the curve was the locomotive engineer losing situational awareness during a microsleep.

Safety issues identified included the control of locomotive engineer hours of duty, fatigue management, and the ability of the vigilance system to overcome a short-term attention deficit in sufficient time to prevent this type of occurrence.

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.

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Abbreviations

hr	hours(s)
kg	kilogram(s)
kg/m	kilograms per metre
km	kilometre(s)
km/h	kilometres per hour
LE	locomotive engineer
m	metre(s)
mm	millimetre(s)
MNPL	Marton-New Plymouth Line
POD	point of derailment
t	tonne(s)
Tranz Rail	Tranz Rail Limited

Data Summary

Train type and number:	express freight (milk train), Train 540
Date and Time:	26 November 2000, at approximately 0105
Location:	60.721 km Marton-New Plymouth Line (MNPL)
Type of occurrence:	derailment
Injuries:	nil
Damage:	extensive to 10 derailed wagons and 100 m of track
Operator:	Tranz Rail Limited (Tranz Rail)
Investigator-in-charge:	R E Howe

1. Factual Information

1.1 Narrative

1.1.1 On Sunday, 26 November 2000, Train 540 was a scheduled express freight milk train between Longburn and Whareroa (the private siding servicing the Kiwi Dairy Company near Hawera). The train consisted of 2 diesel electric locomotives (DFT 7104 and DFT 7158) and 16 "OM" class milk tanker wagons for a total load of 910 t and length 224 m, and was crewed by a locomotive engineer (LE).

1.1.2 The LE booked on at Palmerston North at 2140 on Saturday, 25 November, and at 2215 he took over from the crew who had arrived on the Palmerston North loop with Train 540 from Longburn.

1.1.3 The LE obtained a track warrant for the section from Marton through to Wanganui and at 2230 Train 540 departed Palmerston North. Arrival at Wanganui was at about 2345 having had no train crossings on the way. A new track warrant was issued for travel between Wanganui and Kai Iwi, and the train proceeded to Kai Iwi (at 57.6 km MNPL) and berthed in the loop at approximately 0017 on Sunday 26 November to cross Train 547.

1.1.4 The LE had a cup of coffee and read a magazine for about 40 minutes while he waited for Train 547 to cross. At 0100 Train 540 departed Kai Iwi with a track warrant for the section Kai Iwi to Whareroa.

1.1.5 The LE stated that with a load of only 910 t compared with the maximum allowable load of 1150 t for 2 DFT locomotives (the last 4 OM wagons were empty) he was able to accelerate up the gradient on departing Kai Iwi, notching up as he went. He recalled resetting the vigilance device[1] as the train climbed the gradient, and noted that the speed was about 40 km/h, which was less than the posted speeds for the curves that were being negotiated at the time.

1.1.6 He recalled negotiating the 40 km/h curve near the top of the gradient but could not remember either travelling along the down-hill straight leading from the crest, or resetting the vigilance device in this area.

1.1.7 The LE stated that his next recollection was of a "jolt" and looking at the speedometer. which read 70 km/h. He realised that the train must have been descending and travelling too fast, and was aware of travelling around a curve but was unaware of his exact location.

1.1.8 He immediately shut off the power and applied the automatic brake to about half full service application. The brake valve kept exhausting and he knew that either the train brake pipe had broken or the train had parted. He looked towards the rear of the train to ascertain its condition, but because of the darkness he could not see anything.

1.1.9 The LE recalled that after applying the brakes, the train travelled around 2 right-hand curves, then a left-hand curve and into the next right-hand curve before it came to a stop just past the 61 km peg. Meanwhile, the vigilance alarm had been activated in Train Control (automatically by the sudden loss of brake pipe air) and by the time the train had stopped, the train controller had contacted the LE on the train radio to enquire if everything was all right.

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[1] The vigilance device went through a cycle of a light illuminating every one minute if no controls were touched. If there was no response to the light in 10 seconds a buzzer sounded in the cab. If there was still no response in the next 10 seconds emergency braking was automatically applied and an alarm sounded in Trail Control. The LE could reset the device at any time by moving a control or pressing the cancel button.

1.1.10 The LE, after securing the locomotive and realising that he had only one wagon attached, walked back along the track to the derailed wagons and advised Train Control of the situation. He then returned to the locomotive and reversed his train back to be closer to the derailment site, a movement which was not carried out in accordance with Tranz Rail's Rule 174, provisions for propelling on the main line.

1.2 Site information

1.2.1 The derailment occurred in a 200 m radius right-hand curve, with the wagons derailing to the outside (left) of the curve.

1.2.2 The 2 DFT locomotives and the next wagon (OM323 loaded with milk) remained connected and on the track. The following 10 loaded OM wagons had detached from the train and derailed down the embankment to the left-hand side of the track. The next wagon (OM110 loaded with milk) had the leading bogie derailed but remained coupled to the following 4 empty OM wagons, which had remained on the track. These last 5 wagons had come to rest just short of the derailment area.

1.2.3 There were no marks on the rail head in the area of the derailment to indicate that a wheel flange had traversed across the rail head. The first derailment mark was an angled light scour mark across the top face of a sleeper and 400 mm outside the left rail at 60.721 km.

1.3 Locomotive event recorder

1.3.1 The locomotive event recorder was extracted from DTF7104 and the log showed the following information:

- on departing Kai Iwi, the train progressively powered up to a level of notch 5 and attained a speed of about 34 km/h after 2 minutes
- the train was then powered up to notch 8 and the speed was maintained for a further 2.75 minutes
- while still in notch 8 the train then accelerated up to 75 km/h over the next minute
- the train brakes were then applied bringing the locomotives to a stop in one minute
- while in notch 8 the vigilance device light in the locomotive was activated 3 times at 50-second intervals, and cancelled within 2 to 3 seconds, the last time being at the final brake application at a speed of about 70 km/h. Train speed reached a maximum of 75 km/h before dropping rapidly, due to the brake application.

1.4 Track details

1.4.1 The track in the area of the derailment consisted of 1998, 50 kg/m rail welded into 38 m lengths on 1984, treated pinus radiata sleepers. All fastenings were tight. The ballast section in the derailment area had been disturbed as a result of the derailment but either side it was up to full section of clean crushed metal.

1.4.2 The track proceeding north from Kai Iwi station climbed a 1 in 41 incline known as the Kai Iwi bank. The incline was about 1.6 km in length and negotiated a series of tight radius curves, the tightest of which was 140 m radius just before the crest of the incline. The alignment at the crest and for approximately 0.9 km on the following 1 in 54 down-grade was straight, before reaching the 200 m radius right-hand curve on which the train derailed. From there, the alignment followed a series of tight radius curves for the next 4 km.

1.4.3 The cant[2] in the body of the curve up to the point of derailment (POD) was measured after the derailment and varied between a maximum of 48 mm and a minimum of 24 mm but the variation did not produce any twists[3] beyond acceptable maximums (that is, the variation in cant was progressive and not sudden).

1.4.4 The track alignment was also measured using offset measurements from a defined chord length. These were taken at one metre intervals for 105 m prior to the POD. The specified offset for a 10 m chord of a 200 m radius curve was 63 mm and Tranz Rail's tolerance range was between 42 mm and 84 mm. The alignment was within this range except for a point 11 m prior to the POD where the versine measurement peaked at 98 mm.

1.4.5 The track gauge through the body of the curve measured between a maximum of 1086 mm and a minimum of 1070 mm. Tranz Rail's specified gauge for 200 m radius curves was 1074 mm with a maximum upper maintenance limit of 1092 mm.

1.4.6 The derailment curve and the curve preceding it were posted with their appropriate curve boards and curve warning boards. These were:

- 140 m radius curve preceding the derailment curve (near the top of the incline) 40 km/h
- 200 m radius derailment curve 50 km/h

1.4.7 The EM80 track recording run carried out in the area on 9 August 2000 recorded only secondary gauge faults. No cant, twist or alignment faults were recorded.

1.5 Milk-tanker wagons

1.5.1 The class "OM" milk tanker wagons were modified by Tranz Rail to service milk supplies to the Kiwi Dairy Company. The tanks were constructed from heavy gauge stainless steel, and were 2.4 m diameter, and 11.5 m long, with no internal baffles. The volume of each tank was 52 000 litres.

1.5.2 The filling of the tank wagons from silos at Longburn was a Tranz Rail responsibility. The correct level of milk in each tank wagon was achieved by an automatic metering device that limited the volume of milk in each tank to 50 500 litres, giving a 3% ullage.[4]

1.5.3 The milk tanks were mounted on an under-frame bogie chassis. The tare weight was 13 000 kg and the maximum allowable load 59 000 kg. Tranz Rail advised the overall centre of gravity of the loaded milk tanker wagon was conservatively calculated to be 2.024 m above rail level.

1.6 Factor of safety against overturning

1.6.1 The factor of safety against overturning of a rail vehicle is the ratio of the speed at which rollover is calculated to occur to the authorised speed for the curve radius. Overturning will occur when the factor of safety is less than 1.0. The higher the factor of safety the more resistant a rail vehicle is to overturning due to excessive speed in a curve.

1.6.2 Figures supplied by Tranz Rail gave the following comparisons of the estimated centre of gravity and the ratio of rollover speed to curve speed as applied to a theoretically perfect 50 km/h curve:

[2] The height of the outside rail above the inside rail on a curve.
[3] A defined cant variation over a specific distance related to axle spacings.
[4] The amount by which a container falls short of being full.

Wagon	Estimated height of the Cof/G above rail level	Factor of safety
HWT without hungry boards[5] (wood chip)	1.95 m	1.73
HWT with hungry boards[6]	2.10 m	1.75
IA with 9'6" containers	1.99 m	1.69
JF (steel coil)	1.95 m	1.73
JT (newsprint)	1.88 m	1.79
OM – LSM (milk tankers)	2.03 m	1.66
UCA (tank wagon)	1.90 m	1.78
UCG (LPG tanker)	1.72 m	1.96
UK with 9'6" containers	1.93 m	1.75
ZG (box wagon)	1.69 m	1.99
ZW (well deck, paper)	1.75 m	1.93

1.7 Personnel

1.7.1 The LE of Train 540 had 29 years' railways experience, starting as a locomotive trainee in Palmerston North. He obtained his second grade driver's ticket in 1977 and his first grade ticket in 1983. His initial experience was as a locomotive assistant, progressing to shunt services, slow freight trains, and then to express trains and passenger trains. He held a current operating certificate.

1.7.2 The LE said that he had no financial, domestic or health problems on his mind that disturbed his normal sleep, and that he did not feel tired prior to, or during his shift.

1.7.3 The LE commented that he had recently been having trouble with concentration. He had been aware of a fatigue awareness programme organised by Tranz Rail but because of conflicting shifts at the time training was offered to him, he could not attend. He was not aware of any written material from Tranz Rail covering the course.

1.8 Sleep/wake information

1.8.1 The LE's reported "blank" period prompted a close look at the possible role of fatigue in this incident. The Commission engaged Associate Professor Philippa Gander PhD, an internationally recognised sleep and fatigue management expert, to assist in analysing the possibility that sleep loss and fatigue were causal factors, and her input is included in Sections 2.3 and 2.4.

[5] Hungry boards are an extension to the wagon side height to increase capacity.
[6] The HWT with hungry boards has a maximum speed to 35 km/h and the factor of safety is based on this speed.

Work history

1.8.2 The LE was on leave during most of November 2000. His rostered hours on his return on 21 November are shown below (the actual hours worked are shown in parentheses)

Dates in November	Start (hr)	Finish (hr)	Hours Worked
Tuesday 21 Wednesday 22	2030 (2030)	 0550 (0615)	9.75 (standby shift worked)
Wednesday 22 Thursday 23	2030 (2030)	 0520 (0730)	11
Thursday 23 Friday 24	2105 (2105)	 0540 (0615)	9.2
Friday 24 Saturday 25	2120 (2120)	 0550 (0625)	9.1
Saturday 25 Sunday 26	2140 (2140)	 derailment at 0105	

1.8.3 After booking off his night shift at the locomotive depot at 0625 on Saturday, 25 November, the LE took about 7 minutes to travel to his home on the outskirts of Palmerston North. The LE said that he went straight to bed without any breakfast, which was his usual practice.

1.8.4 He estimated that he may have taken half an hour to get to sleep, woke at about 1230 and rose at about 1300. He had a hot drink and returned to bed about 1600 and "probably drifted off to sleep" until he rose again at 1820. He then had dinner and "rummaged around home", relaxed and watched TV until he departed for his shift starting at 2140.

1.8.5 He said that this was his normal summer sleep pattern while on night shifts. In winter time he could sleep right through but found this difficult in summer time because of the heat, and altered his sleep pattern accordingly.

1.8.6 The LE's self-reported sleep times from 20 November were:

Date	Asleep	Awake	Nap	Total sleep
Mon 20/11	2200?	-	-	-
Tues 21/11	-	0700?	-	9 hr?
Wed 22/11	0700	1330	1 hr (1500-1600)	7.5 hr
Thurs 23/11	0800	1400	2 hr (1600-1800)	8.0 hr
Fri 24/11	0700	1230	2 hr (1600-1800)	7.5 hr
Sat 25/11	0700	1230	2.3 hr (1600-1820)	7.8 hr
Sun 26/11				

1.8.7 Figure 1 shows the sleep/wake pattern for the LE based on sleep information available from 20 November and work patterns leading up to the derailment shift. The derailment occurred on his 5th consecutive night shift after a period of annual leave. All 4 preceding shifts ran longer than rostered because of late running of trains. Across the 4 rostered shifts prior to the derailment shift, the LE had worked 3 hr 45 minutes longer than was rostered. When questioned about the late running he commented, “We are used to it; we rarely get home on time.”

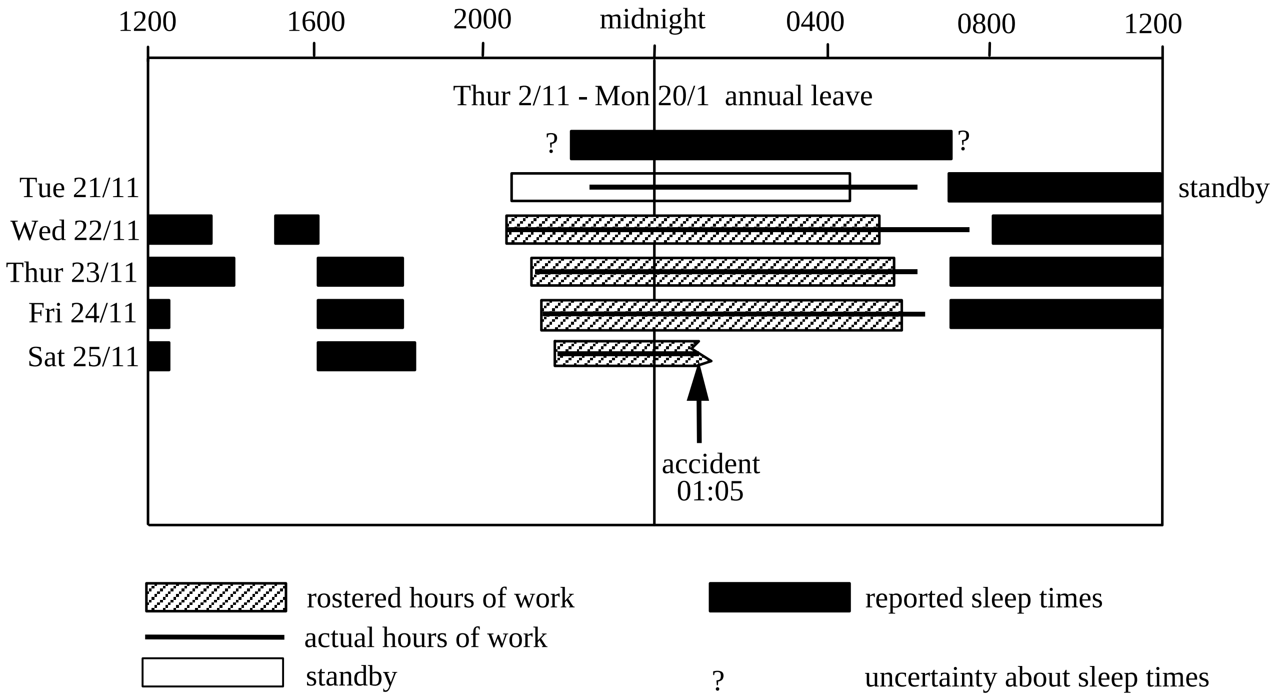

Figure 1
Sleep/wake pattern

1.9 Weather

1.9.1 The weather during the night of the derailment was calm and clear, with no cloud.

1.10 Previous occurrences involving attention loss

1.10.1 The Commission has investigated 2 other recent occurrences involving reported microsleeps with a possible link to sleep loss and fatigue. These were:

- Rail Occurrence Report 00-115, Westmere, a locomotive rollover on 22 September 2000 following a high speed entry into a restricted speed curve (published with this report)
- Rail Occurrence Report 00-121, Middleton, a 2-train collision on 8 December 2000 (published with this report).

In addition, Rail Occurrence 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 The derailment

2.1.1 The train speed and lack of marks on the rail head were consistent with an overturning derailment due to centrifugal force on a curve.

2.1.2 The factor of safety against overturning for a moving wagon is influenced by a number of parameters:

- the higher the centre of gravity of a wagon, the greater will be the toppling effect of centrifugal force on the wagon as it negotiates a curve
- the centrifugal force imposed on a wagon as it negotiates a curve varies as the square of the speed. That is, all other things being equal, a doubling of speed will increase the centrifugal force acting on the wagon by 4 times
- the centrifugal force acting on wagons varies inversely to the radius of the curves they negotiate. For this reason tighter radius curves have maximum allowable speeds imposed to limit the effect of centrifugal force. Curve speed boards were posted on those curves where the curve speed was less than the line speed
- cant is placed on curves to assist in off-setting the effect of centrifugal force. More cant is placed on tighter radius curves than on curves of bigger radius
- any lateral movement of a wagon bogie with respect to the chassis and any roll of the body on the wagon springs will produce an eccentricity that will effectively reduce the overturning safety factor
- the movement of load on a moving wagon due to insecure fastenings or excessive ullage can interact with the wagon/track dynamics to promote instability. In the case of loaded OM wagons with 3% ullage, load movement was not a factor as indicated by the lack of a need for baffles in the tanks.

2.1.3 The Tranz Rail maximum allowable alignment tolerances for a 200 m radius curve could vary between versines of 42 mm and 84 mm over a 10 m chord length. The instantaneous radius for an 84 mm versine equates to a 150 m radius curve, and for a speed of 50 km/h would reduce the factor of safety for an OM wagon to 1.5. The actual maximum versine of 98 mm at 11 m before the POD was unlikely to have been materially affected by track damage following the derailment. It equated to an instantaneous radius of 130 m which further reduced the factor of safety to 1.42 for a speed of 50 km/h. The effect of negotiating the curve at the actual speed of 70 km/h instead of 50 km/h reduced the factor of safety and resulted in the wagons overturning.

2.1.4 The centre of gravity of the OM wagon was the highest of the representative wagons running at normal speed, as detailed in 1.6.2, with the corresponding lowest factor of safety against overturning.

2.1.5 A subsequent derailment involving a unit milk train hauling OM wagons occurred near Maxwell on 17 January 2001. The Commission elected not to investigate this derailment, and Tranz Rail’s internal report is not complete. However, Tranz Rail advised that the speed of the train and the dynamic interaction between the wagons and the track have been identified as key elements in the derailment.

2.1.6 A factor of safety of 1.66 should provide an acceptable margin for safety for normal operations. As an interim safety precaution, Tranz Rail have restricted the speed of loaded OM wagons between Marton and Whareroa to 55 km/h until they complete an investigation into the riding characteristics of these wagons. No safety recommendations have been made in this regard.

2.1.7 The derailment at Kai Iwi occurred due to a combination of:

- excessive speed on a curve
- a local peak in alignment near the entrance to the curve
- the relatively high centre of gravity of the OM wagon.

It is likely that the jolt caused by the locomotives passing over the misalignment near the entrance to the curve was the stimulus that woke the LE from a microsleep. The misalignment triggered the wagon dynamics that, combined with the train speed, resulted in the overturning derailment. If the track had not been misaligned it is likely that Train 540 would have successfully negotiated the curve entrance at the speed it had by then reached. However, it is also likely that the LE would have remained effectively asleep and that the train would have continued to increase speed and derail a short time later at a less severe point of curvature in the curve, or following curves, regardless of the height of the centre of gravity of the OM wagons.

2.2 Control of Train 540

2.2.1 Analysis of the locomotive event recorder output showed the LE progressively throttled up as his train ascended the Kai Iwi bank, reaching notch 8 some 2 minutes 40 seconds before the derailment. He then responded to a visual vigilance alarm in 2 seconds, one minute and 45 seconds before the derailment, and a further visual vigilance alarm in 3 seconds, 55 seconds before the derailment. During those last 55 seconds the train speed increased from approximately 35 km/h to 70 km/h at derailment. The next visual vigilance alarm was automatically cancelled at 3 seconds by the brake application when the LE was jolted awake. The LEs brake application and the loss of brake pipe air when the train parted as the wagons overturned occurred at about the same time.

2.2.2 The LE’s lack of memory of events as he crested the grade, and the increase in train speed, were consistent with a microsleep for up to 55 seconds.

2.2.3 The LE’s action in propelling his train back to the derailment site after stopping contravened Rule 174, but had no hazard potential in the circumstances.

2.3 LE fatigue

Method for assessing fatigue

2.3.1 Fatigue assessment was based on a method developed by the US National Transportation Safety Board and the NASA Fatigue Countermeasures Program [7]. The method seeks information on the following factors known to produce fatigue-related performance impairment:

- extended wakefulness
- acute sleep loss and cumulative sleep debt

[7] National Transportation Safety Board 1994. Uncontrolled collision with terrain. American International Airways Flight 808. *Aircraft Accident Report 94/04*.

- presence of a sleep disorder
- critical times in the daily cycle of the circadian body clock.

2.3.2 Falling asleep uncontrollably becomes inevitable when biological sleepiness[8] exceeds a certain threshold. The factors defined in 2.3.1 contribute to the intensity of biological sleepiness and are considered below in relation to this derailment.

Sleep history

2.3.3 The accuracy of information on the LE's sleep history was limited by the following factors:

- subjective reports of sleep duration and timing are not necessarily reliable
- over a week had elapsed from the first of the sleep episodes being recalled to the time of the interview
- the derailment had occurred 3 days prior to the interview with the LE.

Time of day

2.3.4 Biological sleepiness waxes and wanes across the daily cycle of the circadian body clock. The derailment occurred around 0105, a time in the cycle of the circadian body clock when the biological urge to fall asleep is rising steeply towards its daily maximum. Previous studies of Swedish LEs[9] have confirmed that LEs can fall asleep uncontrollably in the cab in the early hours of the morning.

Time on shift

2.3.5 At the time of the collision the LE had been on shift for about 3 hr 25 minutes, which may have contributed to his decreased alertness and increased biological sleepiness.

Duration of continuous wakefulness

2.3.6 Figure 1 shows the LE had a pattern of sleeping as soon as he got home in the morning, and then taking a further nap in the afternoon before going back to work. This "split sleep" pattern is common among night workers. There is considerable scientific evidence indicating that the sleep period prior to night duty is effective in improving alertness and performance across the night shift. The derailment occurred about 6 hr and 40 minutes after the end of the LE's last reported sleep period. Thus, extended wakefulness would not have contributed to his biological sleepiness at the time of the derailment.

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[8] Biological sleepiness is effectively a message from the brain that it requires sleep, similar to hunger indicating a need for food or thirst indicating a need for water. Biological sleepiness eventually becomes overwhelming leading to falling asleep uncontrollably.
[9] Torsvall L and Akerstedt A, 1987. Sleepiness on the job: continuously measured EEG changes in train drivers. Electroencephalography and Neurophysiology. 66: 502-511.

Prior sleep loss

2.3.7 Insufficient prior sleep increases biological sleepiness at all times in the circadian body clock cycle. The LE's last nocturnal sleep prior to beginning night shift was reported to be about 9 hr long. From his reported sleep times he averaged about 1.3 hr less sleep across the 4 night shifts preceding the derailment shift. This sleep pattern would cause him to have an accumulated sleep debt of about 5.2 hr going into the derailment, assuming he was fully rested at the end of his period of leave. Based on his preceding work pattern, it seems very likely that the LE was experiencing some effects of a cumulative sleep debt at the time of the derailment.

Presence of a sleep disorder

2.3.8 Although the LE commented that for some time he had been having problems with concentration while driving trains, there was nothing to indicate that he was suffering from a sleep disorder that could have compromised the quality of his sleep.

Possibility of a microsleep

2.3.9 The combination of the following factors makes it very probable that the LE's biological sleepiness reached a level where he fell asleep unintentionally and uncontrollably:

- the time of the collision (around 0105)
- the fact that he had been on duty for over 3 hr
- the likelihood that he was experiencing the effects of a cumulative sleep debt (being on his 5th consecutive night shift).

2.3.10 What is more difficult to explain is why the LE fell asleep on this particular trip. He had driven the same trip "hundreds of times". He had already driven it 4-5 times in the 2000 milk season, it was good weather and he was running about on schedule. He was on his 5th consecutive night shift after a period of extended leave, during which one might assume he was well rested. By his own account, his sleep pattern leading up to the derailment shift had been entirely usual. It cannot be excluded that he had previously experienced microsleeps on the milk train trip, but not on sections of track where his continuous vigilance was critical to the safe operation of the train.

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

2.4.1 The following table compares 3 recent incidents (see paragraph 1.10.1) 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 hr	3 hr 25 mins	6 hr
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 hr)	4/4 (average 55 min)	4/5 (average 38 min)*

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

2.4.2 These incidents have in common that they occurred at least 3 hr into a night shift that was the 5th to 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.

2.4.3 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 apparently 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 apparently 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.

2.4.4 In general, night workers find it difficult to obtain extended sleep during the day. Typically, daytime sleep periods are about a third shorter than nighttime sleep periods. 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, a recent expert panel recommended that truck drivers should work no more than 18 hr between 0000-0600 before having 2 consecutive nights of sleep[10]. Air traffic controllers are generally limited to 2 night shifts in a row[11].

2.4.5 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. Thus, late-running night shifts further restricted the opportunities for each of these LEs to sleep during the biologically preferred time, and may have increased their sleep debt at the time of the incident. Late running after any shift also reduces the amount of time available for all activities away from work, and may increase the pressures on an LE to restrict his sleep in order to participate in other areas of life.

3. Findings

Findings and safety recommendations are listed in order of development and not in order of priority.

3.1 Train 540 derailed primarily due to excessive speed around a restricted speed curve.

3.2 The excessive speed was due to the LE's loss of attention, consistent with his having fallen asleep.

3.3 A local peak in the track alignment and the high centre of gravity of the OM wagons lowered the factor of safety against overturning, but without their influence it is likely a derailment would still have occurred further down the grade.

3.4 The LE was probably experiencing the effect of an accumulated sleep debt at the commencement of his shift on Saturday, 25 November 2000.

3.5 The derailment occurred at a time when the LE's biological sleepiness would be expected to be increasing rapidly towards its daily maximum.

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[10] Fatigue Expert Group 2001. *Options for Regulatory Approach to Fatigue in Drivers of Heavy Vehicles in Australia and New Zealand.* National Road Transport Commission: Law Courts, Victoria, Australia.

[11] Gander PH 2001. Fatigue management in air traffic control: The New Zealand approach. *Transportation Research (in press)*

3.6 The LE's increase in sleepiness due to the daily cycle of his body clock would have been exacerbated by his prior sleep loss, and by his being 3.5 hr into the shift.

3.7 Although the Tranz Rail fatigue control regime had identified potential fatigue contributors and defined parameters and initiated actions to limit the effects of fatigue and improve alertness management, it had not been fully effective. Programmes to improve alertness management had reached only 35% of LEs over 3 years, and not the LE of Train 540.

3.8 The current vigilance system did not provide an effective defence against short microsleeps and the possibility of similar consequences.

3.9 The LE was appropriately certified for his duties, and his compliance monitoring met Tranz Rail safety observation procedure requirements.

4. Safety Actions

4.1 Tranz Rail advised they intend to commission Associate Professor 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. As an interim step, a number of LEs who have shown signs of lapses of concentration have been taken through the existing package.

4.2 Before returning to duty after the incident the LE was put through a one day Alertness Management course. He was also referred to the Sleep Centre at Wakefield Hospital for assessment.

5. Safety Recommendations

5.1 Report 00-115 regarding an overturning derailment at Westmere on 22 September 2000, published with this report, made 3 safety recommendations relating to control of hours of work, Alertness Management training and the operation of vigilance devices. These safety recommendations were made to the managing director of Tranz Rail and are equally applicable to this incident. They were:

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

5.2 On 26 June 2001 the Commission recommended to the managing director of Tranz Rail that he:

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)

5.3 On 16 July 2001 the managing director of Tranz Rail replied, in part:

> Tranz Rail completed a review of recent literature relating to factors contributing to biological sleepiness in Locomotive Engineers during April 2001.
>
> This review identified consistent opinion regarding sequences of night shifts. More specifically, there is now a view that the number of night shifts in rotating rosters should be confined to three, and in the case of permanent night shift, six. Tranz Rail Locomotive Engineers work to rotating rosters.
>
> The literature also recognised the importance of a recovery period following a sequence of night shifts to restore "sleep debt" accumulated during these shifts.
>
> The information was first reviewed by the Locomotive Engineers' Council (a joint Tranz Rail/Rail Maritime and Transport Workers Union forum) at their 10/11 May meeting. It has subsequently been decided to prepare rosters with sequences of night shifts confined to three followed by mandatory time off. These rosters will be piloted in four depots.
>
> Toward the end of the pilot period (likely to be several months) Locomotive Engineers working these rosters will be surveyed to identify if they have found the revised rostering principles more beneficial.
>
> It is expected the pilot period will commence during August 2001 and the review will take place in late October/early November 2001.
>
> A final decision regarding a permanent change to these rostering principles will be made following an analysis of the results of the pilot and further discussion within the Locomotive Engineer's Council.

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Hon. W P Jeffries
Chief Commissioner