Report 00-115

Train 521

derailment

Westmere, near Wanganui

22 September 2000

Abstract

On Friday 22 September 2000, at about 2338, express freight Train 521 derailed when travelling too fast for the first curve encountered descending the 1 in 35 down grade on the Westmere bank. The 2 locomotives were severely damaged when they overturned following the derailment. The locomotive engineer received only minor injuries.

The reason for the excessive speed was the locomotive engineer's loss of 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 allow effective corrective action to be taken.

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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List of Abbreviations

hr	hour(s)
kg/m	kilograms per metre
km	kilometre(s)
km/h	kilometres per hour
LE	locomotive engineer
m	metre(s)
MNPL	Marton-New Plymouth Line
POD	point of derailment
RMTU	Rail and Maritime Transport Union
t	tonne(s)
TW	track warrant
Tranz Rail	Tranz Rail Limited

Data Summary

Train type and number:	express freight, Train 521
Date and time:	22 September 2000**,** 2338
Location:	Westmere, near Wanganui
Type of occurrence:	derailment
Persons on board:	crew: 1
Injuries:	nil
Damage:	major damage to the 2 locomotives and 4 of the derailed wagons
Operator:	Tranz Rail Limited (Tranz Rail)
Investigator-in-charge:	R E Howe

1. Factual Information

1.1 Narrative

1.1.1 On Friday 22 September 2000, express freight Train 521 was operating a scheduled southbound service on the Marton-New Plymouth Line (MNPL) under the track warrant (TW) train control system.

1.1.2 The train consist was locomotives DFT 7064 and DC 4006 (long hood leading) coupled in multiple[1] and 8 wagons. The gross weight of the train was 200 t and the length was 160 m. The train was crewed by a locomotive engineer (LE).

1.1.3 The LE commenced his shift at New Plymouth at 1950. He travelled by car to Stratford, where he joined Train 521 and departed at 2105 on his scheduled southbound trip.

1.1.4 The initial TW took him to Whareroa, where 15 minutes were spent shunting, followed by a further TW to Patea to cross Train 546. Train 546 arrived immediately after Train 521 and Train 521 was underway within 5 minutes.

1.1.5 TW 67 was issued for Train 521 to proceed from Patea to Wanganui, with a requirement to call train control at Waitotara and Kai Iwi. The LE called Train Control at Waitotara and Kai Iwi as he proceeded south.

1.1.6 At about 2335 Train 521 was climbing the 3 km long 1 in 40 upgrade towards the top of the Westmere bank before descending the 5 km long 1 in 35 downgrade to Wanganui.

1.1.7 The following is the sequence of events as remembered by the LE as Train 521 climbed the grade and started to descend the other side:

- train speed was 60 km/h at the foot of the grade
- the speed progressively reduced as the curves on the grade were negotiated
- the LE's thoughts were on a possible crossing with Train 522 at Wanganui and the chance for a tea break
- near the top of the grade his train speed dropped to 20 km/h, at which time he was retrieving his meal and cup from his bag
- at this time the vigilance alarm sounded, and he cancelled by pushing the button
- the train "cruised up" towards the top of the bank and he saw the Intermediate Board for Westmere ahead of him (the board was at 49.14 km, some 1750 m before the point of derailment (POD))
- he recalled making a mental note to have dynamic braking [2] engaged when he reached the Board and then "that was the last I can remember, my eyes must have just shut"
- that was his last recollection before he "woke up" on straight track some 200 m before entering a right-hand 135 m radius curve, which had an authorised speed of 40 km/h
- he noticed his train speed was 68 km/h and momentarily throttled up to notch 7 before throttling back and making a full service brake application
- his brakes "grabbed" as he rounded the right-hand curve under the overbridge (see Figure 1), following which he heard a "big bang" and felt his locomotive riding on the sleepers before leaning to the left and overturning

[1] Locomotives coupled in multiple are both used to haul the train.
[2] Dynamic braking is the use of the traction motors as generators to assist downhill braking.

1.1.8 The 2 locomotives and the 5 leading wagons derailed and came to rest at various positions on the left side of the track or straddling the track. The 3 trailing wagons remained on the rails just beyond the POD.

1.1.9 The LE remained conscious during the derailment and overturning. Almost immediately the locomotive came to rest the train controller rang on the train radio (alerted by the alarm [3] in train control). The LE confirmed he was unhurt apart from a bruised shoulder. On finishing his report to the train controller he exited the cab through a window.

1.1.10 The LE advised the Police that the train had been carrying hazardous goods, and assisted in obtaining information on the type of goods, before travelling home in a taxi.

1.1.11 The hazardous goods were bitumen and bitumen primer, carried in a container in the second wagon in the consist. This wagon finished upright straddling the tracks at the north end of the derailment site, with the security of the load unaffected.

1.2 Site evidence

1.2.1 A recent heavy wheel marking was present on the running edge of the left rail at 48.394 km, with a light wheel marking crossing the rail head to the outside of the rail.

1.2.2 The track at 48.394 km was in a small cutting. The cutting face on the left side from 5 m to 20 m beyond the wheel mark showed increasing evidence of impact.

1.2.3 A full track geometry measure-up was carried out, based on 48.394 km as the POD.

1.2.4 DFT 7064, the leading locomotive, came to rest on its side about 110 m from the POD on the left side and some 5 m from track centre (see Figure 2). DC 4006 was still attached, also on its side. The cab of DC 4006 was separated from the locomotive and came to rest about 50 m from the POD on the left side and some 30 m from track centre (see Figure 3).

1.2.5 The area was under a 40 km/h permanent speed restriction because of tight curves. A 40 km/h speed board was in place at 48.85 km, 176 m before the POD.

1.2.6 The track was 50 kg/m heavyweight rail on concrete sleepers which had been laid only days before the derailment.

1.3 Locomotive event recorder

1.3.1 The Kaitiaki locomotive event recorder data was downloaded and supplied for analysis.

1.4 Personnel

1.4.1 The LE of Train 521 had 15 years service, of which 9 were as a grade 1 LE. He had been based at New Plymouth for all of this service. He held a current operating certificate for his duties.

1.4.2 The LE's last theory examination for recertification was on 8 August 2000 and his last formal A level observation was on 14 August 2000. He had also been subject to a formal B level observation on 22 September 1999.

[3] Set off by the disconnection of the train brake pipe

Figure 1
Looking south from the POD at the derailed locomotives in the background

Figure 2
The cab of DFT 7064 (looking north towards the POD)

Figure 3
Looking north from the cab of DFT 7064 at coupled DC 4006 and the DC cab in the background

1.5 Rostering

1.5.1 The Tranz Rail roster system was built around base rosters compiled centrally with Rail and Maritime Transport Union (RMTU) input. They were compiled using defined principles of fatigue management, with fortnightly rostered shifts at or about 80 hr (within 76 to 83 was considered acceptable by Tranz Rail). Relief shifts and standbys were built in to allow for annual leave, sickness and operational demands.

1.5.2 Some week or so before shifts commenced, mini rosters were compiled for each LE, which included changes to the base roster to accommodate the staff available and operating demand. Actual hours worked could vary from these due to late running and other operational factors on the day.

1.5.3 Tranz Rail was in the process of altering the headquarters of Taranaki-based LEs at the time of this incident. Due to the incomplete facilities at Stratford (the new headquarters for the majority of New Plymouth LEs) an interim Stratford roster had been introduced in April 2000, and revised in September, without changing headquarters. Along with other New Plymouth domiciled LEs the LE was booking on at New Plymouth and then using Tranz Rail transport to get to and from Stratford (approximately 35 minutes each way). His understanding was that this was part of his allocated shift from New Plymouth to New Plymouth and his timesheet was completed accordingly as to hours worked. This continued the method of booking hours he had been using prior to the proposed change of headquarters, which had included any necessary travel to and from New Plymouth within his shift. Once Stratford facilities were completed the LE, who had elected to retain his home at New Plymouth, was to be booked on and off at Stratford and travel in his own time.

1.5.4 In response to a request by the investigator in March 2001, Tranz Rail supplied details of hours worked by all Taranaki-based LEs. Part of this information included details of the hours worked by the LE involved during the fortnight prior to the incident as detailed in Section 1.6.3. The hours worked as advised included time spent travelling between New Plymouth and Stratford return. However, when responding to the preliminary report Tranz Rail advised further on 11 June 2001:

> The 35 minutes each way travelling time between New Plymouth and Stratford was essentially a payment recognising the Locomotive Engineer would need to visit New Plymouth depot before travelling to Stratford. It was not included as part of the Locomotive Engineer's rostered shift.

1.5.5 Of the 10 men on the interim Stratford roster at that time, one was under training, and one was on 2 weeks leave. This left 8 LEs to cover the 10 link roster (which included 2 relief shift links and no standby shifts) for the fortnight ending 30 September. Although particular seasonal trains were rostered but not running at the time, this workload relief was countered by a need for a Stratford LE to do second-man duties on the Stratford-Okahukura Line normally carried out by a rail operator. The LE's base-rostered trains for week ending 17 September had been cancelled (6 late shifts, 1530 to 0010 at 52 hours) and he had been reallocated the second-man duties (5 night shifts, 1945 to 0400 at 41.25 hours) on the mini roster.

1.5.6 The following table reflects the actual hours worked by the Taranaki-based LEs during September. The main reason for the high hours for the fortnight ended 30 September was the unavailability of the LE following the incident.

Nominal LE base	Maximum hours worked per fortnight		Percentage of staff exceeding 100 hours per fortnight	
	FE 16/9/01	FE 30/9/01	FE 16/9/01	FE 30/9/01
Stratford* (10 LEs, 8½available)	102.5	119.5	10%	33%
Whareroa (3 LEs, 3 available)	98	123.2	-	67%
New Plymouth (3 LEs, 3 available)	92	100.2	-	33%

* Although Stratford was the nominal base, 6 LEs were domiciled at New Plymouth and booking on and off at New Plymouth on an interim basis.

1.5.7 Tranz Rail had procedures in place for controlling shifts, including maximum shift lengths, shift rotation and time between shifts. Although Section 3, Clause 1.0 of the Tranz Rail "Rail Operating Manual" specified that base rosters were to be constructed at or about 80 hours each fortnight there was no separate control on the maximum mini-rostered hours or the actual hours worked, either in a rostered fortnight or in the fortnight made up of the second week (week B) of a rostered fortnight and the first week (week A) of the next rostered fortnight. In addition there were no procedures in place to control the base-rostered hours in such overlapping fortnights. The fortnight ending 23 September 2000 leading up to the incident was an overlapping fortnight.

1.5.8 Section 3 of the "Rail Operating Manual" also defined 2 key elements of the roster system, standby and relief shifts, and included:

> 4.5.2 STANDBY shifts are placed in master rosters to facilitate relief and to minimise the need for employees to work extra work periods …
>
> 4.5.7 RELIEF shifts will be provided as separate links in a roster to cover holidays recertification, training, sickness, special trains and other special arrangements.

1.5.9 A comparison of the various rosters under which New Plymouth and Stratford LEs were operating during 2000 showed:

	Prior to April 2000	From 30/4/2000	From 3/9/2000
LEs on the roster	12 (New Plymouth)	9 (New Plymouth) 3 (Stratford)	3 (New Plymouth) 10 (Stratford, of which 6 were still domiciled at New Plymouth)
No. of relief shift links	2	2	2
No. of standby shifts built in	5	9	Nil

1.6 Sleep/Wake information

1.6.1 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 likelihood that sleep loss and fatigue were causal factors. Her input is included in section 2.5, paragraphs 2.5.1 to 2.5.20.

Work history

1.6.2 For the fortnight 10 September to 23 September 2000 the LE's rostered hours on his mini rosters, excluding travel New Plymouth to Stratford and return, were 104.7 hr (including a standby day and the day of the incident). This compared to his 101-hr base roster for the same period. The work pattern within the mini rosters was:

- one standby day (nominal 8 hr)
- 5 days night shifts (1945-0400, 8.25 hr nominal)
- one day off
- one day morning shift (1000-1615)
- 5 days night shifts (2025-0615, 9.83 hr nominal with the incident occurring on the fifth shift)
- one day off.

When on standby, staff were required to be near home and contactable for duties within a defined time period. The LE was not called out on his standby day. The morning shift was an additional rostered shift to cover for an LE granted annual leave for a day. This had been offered to and accepted by the LE involved in the incident.

1.6.3 His actual hours of work were:

- one day standby (not called)
- 5 days night shifts (total hours worked each shift, including travel New Plymouth to Stratford, were the maximum allowable 11 hours due to late train running)
- one day off
- one day morning shift (7.25 hr)
- 4 days night shifts of 11.2, 11.0, 12.3, and 11.0 hr respectively, again including travel New Plymouth to Stratford, before the day of the incident. This was also due to late train running.

1.6.4 The 12.3 hr shift worked on Wednesday 20 September resulted from the lack of a relief driver. The LE believed he should have been relieved at Patea to complete his shift at New Plymouth within 11 hr. He continued to Whareroa, at which stage he believed his 11 hr were completed but he still had to return to New Plymouth to book off within his shift time. The train controller asked the LE before arrival at Whareroa whether he would drive a car home to New Plymouth. The LE said no, "I am holding matchsticks under my eyes at the moment", and a taxi was supplied without question. The 12.3 hr shift included his taxi ride back to New Plymouth.

1.6.5 Assuming the LE had completed the fortnight ending 23 September without incident his total hours worked for that fortnight would have been about 119 not counting standby, and 127 hr counting standby.

1.6.6 This roster included working Sunday 17 September, his only normal rostered day off during this fortnight. His longest break from commencement of his shift on Monday 11 September was from 0610 Saturday 16 September to 0930 Sunday 17 September, a period of 27.3 hr. His shortest break was 12.8 hr.

1.6.7 The LE said he was in good health and not under medication at the time of the incident. He was under no particular personal pressures. However, he did comment that his acceptance of an extra shift on Sunday 17 September was unusual and motivated by a need for extra income. He said this was to allow for a purchase of a second car, "mainly because of the shift [of LE headquarters] to Stratford".

1.6.8 The LE had not been through the Tranz Rail Alertness Management program (see 2.5.23), although he could remember a pamphlet "to inform our spouses" about sleep requirements and diet.

Sleep history

1.6.9 The LE used a detached sleepout to minimise disturbance to his day time sleep, and had a routine practice of taking controlled naps when on duty and waiting for a crossing.

1.6.10 The LE's self-reported sleep times from 16 September were:

Date	Asleep am	Awake am	Asleep pm	Awake pm	Nap	Total Sleep
Sat 16/9	06:00?	10:00	19:30	-	-	8.5 hr
Sun 17/9	-	07:00?	20:30	-	-	10.5 hr?
Mon 18/9	-	07:00?	14:00	18:30	-	11.5 hr?
Tue 19/9	07:00	11:00?	14:00	18:00	1 hr	9.0 hr
Wed 20/9	07:00	11:00?	14:00	18:00	1 hr	9.0 hr
Thur 21/9	-	-	13:00	18:00	-	5.0 hr
Fri 22/9	07:00	10:30	13:30	16:30	-	7.5 hr

1.6.11 Figure 4 shows the sleep/wake pattern for the LE based on sleep information available from 16 September.

1.7 Previous occurrences involving reported microsleeps

1.7.1 The Commission has investigated 2 other recent occurrences involving reported microsleeps with a possible link to sleep loss and fatigue, namely:

- Railway Occurrence Report 00-117, Kai Iwi, derailment of a milk train on 26 November 2000 following a high-speed entry into a restricted speed curve (published with this report).
- Railway Occurrence Report 00-121, Middleton, a 2-train collision on 8 December 2000 (published with this report).

In addition Railway Occurrence Report 00-111, Tapuata, involving a TW overrun on 14 June 2000, concluded that a microsleep may have been a factor in the events that occurred, although sleep loss and fatigue were not considered to be contributory (published April 2001).

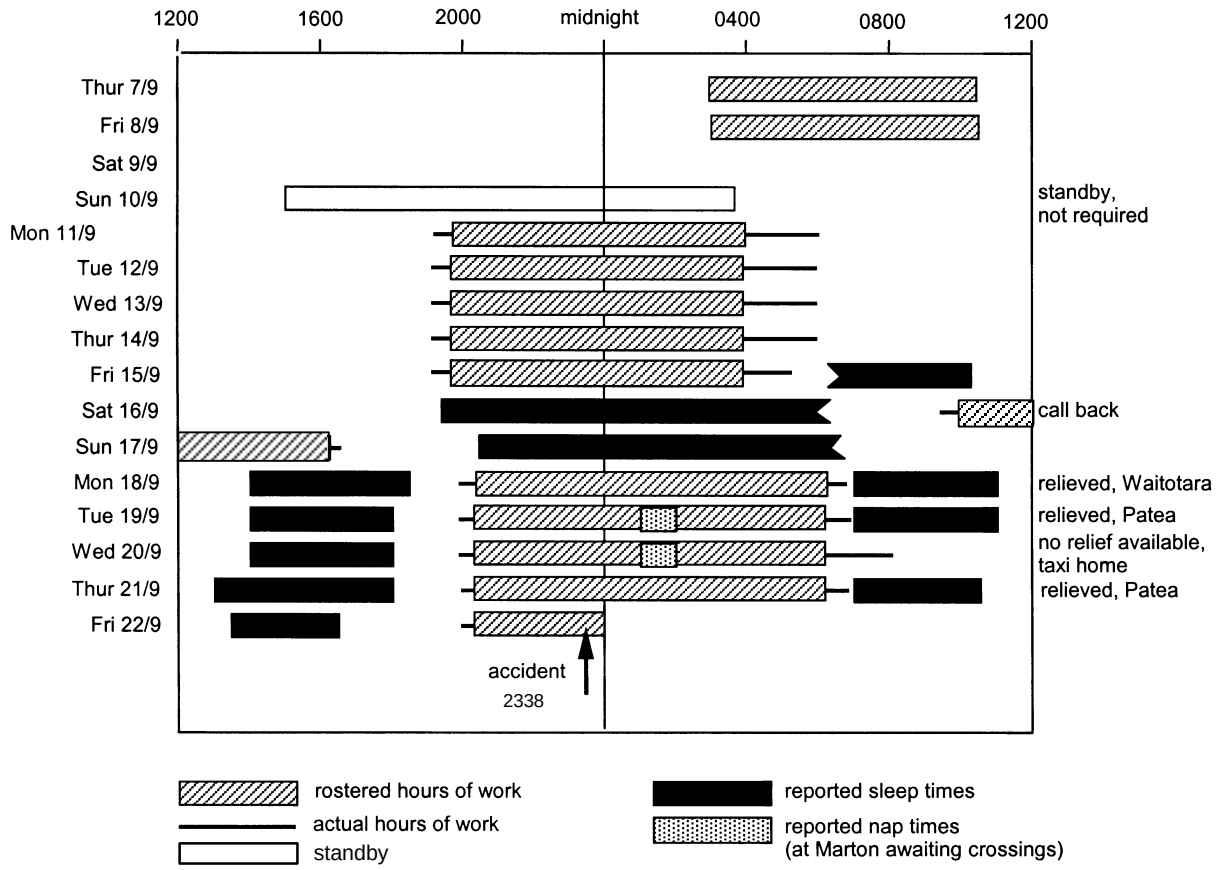

Figure 4
Sleep/Wake pattern

2. Analysis

2.1 The derailment

2.1.1 The event recorder output showed Train 521 was at 48.67 km, some 200 m from the curve entry, and travelling at 72 km/h when a throttle reduction from notch 4 and a brake application were made. Speed rose to 75 km/h maximum before the braking took effect and reduced speed to approximately 65 km/h at the POD.

2.1.2 From the marks on the rail, the impact marks on the cutting face and the LE's memory of events when the derailment occurred, DC 4006 overturned due to centrifugal force during transit around the curve. A rollover derailment of a locomotive at a ratio of actual speed to authorised speed (factor of safety) of 1.63 is a likely outcome. The track measure up and computer-generated output showed no track deficiencies which would have contributed to the derailment.

2.2 Control of Train 521

2.2.1 Analysis of the event recorder output showed the minimum train speed up the grade was 28 km/h at 52.8 km, some 6 minutes before the derailment, following which speed increased. The next lowest speed of 35 km/h occurred at 50.6 km, about 2 minutes 40 seconds before the derailment, and it is likely that the LE was retrieving his meal at this point.

2.2.2 The last throttle or brake application before those associated with entering the derailment curve were at approximately 50.1 km, about 1 km before the Intermediate Board at the top of the grade, 1.43 km from the point of braking at the curve entry, and 1.7 km from the POD. The throttle had been momentarily put from notch 6 to notch 7 at this point, before reducing to notch 4 where it stayed. This is the same sequence the LE thought he had performed just before derailment. It is understandable that his memory differed from the recorded data. It is likely that the LE's loss of attention occurred from 50.1 km to 48.67 km, during an elapsed time of about 2 minutes 16 seconds, but that his attention momentarily returned during this period. Although this may have been induced by his hearing and cancelling the vigilance device at about 49.5 km, when he recalled seeing the Intermediate Board ahead, it is more likely a catalyst such as exiting tunnel 4 or passing over the level crossing just ahead of the Intermediate Board prompted his partial awareness. He was then about 800 m or some 54 seconds from the point of braking prior to the derailment.

2.3 Vigilance response

2.3.1 The event recorder output showed the vigilance response time on DFT 7064 was random between 1-20 seconds [4] on the day before the incident, which was the expected response range. However, from 1652 on 22 September the response was consistent at one second. Post-incident evaluation of the DFT locomotive showed no specific fault which would account for this anomaly.

2.3.2 Post-incident testing by Tranz Rail subsequently established that when a DFT and DC locomotive were coupled in multiple it was possible for generated floating voltages to cause the vigilance alarm to be reset automatically when power was supplied to the vigilance light, and thus remove the stimulus to the LE. Action has been taken to correct this (see Section 4). The LE was not aware of any vigilance alarm problem and reported a buzzer and cancellation shortly before the derailment. Tranz Rail advised that the nature of automatic resetting meant it was "extremely unlikely" that the lights and buzzer would have operated during this period.

2.3.3 It is likely that the LE was experiencing microsleeps for over 2 minutes, but possibly was partially woken or became attentive enough to note the presence of the Intermediate Board ahead before lapsing back to sleep 54 seconds before waking and braking before the curve. Fifty-four seconds was long enough for the train to reach a point where derailment and rollover were inevitable. This questions the suitability of the current fixed time-cycle vigilance device used by Tranz Rail.

2.3.4 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. However, Tranz Rail advised no changes had been made to the fixed time cycle system in use in 1997 as a result of the assessment. Tranz Rail supplied the following update indicating its intention to reactivate the project:

[4] The vigilance device went through a cycle of a light illuminating every one minute if no controls were touched. If there was no response in 10 seconds a buzzer sounded in the cab. If there was still no response in the next 10 seconds braking was automatically applied and an alarm sounded in train control. The LE could cancel the vigilance at any time, either by adjusting the controls or pushing the cancel button, as evidenced by the normal random response.

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.

2.4 Rostering

2.4.1 The LE's understanding, supported by the information supplied by Tranz Rail in Section 1.6.3, was that the 1 hour 10 minute daily travel New Plymouth to Stratford and return formed part of total working hours at the time of the incident, and was therefore part of his shift. (The maximum shift length criteria differentiated between maximum shift length and maximum footplate hours.)

2.4.2 Tranz Rail's later contention that it was not part of the LE's rostered shift is supported by the hours on the relevant base roster and mini roster. The roster hours were based on staff booking on and off at Stratford.

2.4.3 The Commission's view is that no change had been made to the LE's booking on and off station (New Plymouth). Superimposing a Stratford-based locomotive running roster on a New Plymouth-based LE had effectively increased his shift length by 1 hour 10 minutes and the control of rosters and shifts should have taken this into account.

2.4.4 However, the key issue is that the LE was affected by a combination of work-related travel and locomotive driving over a 12-day period. The possibility of fatigue was less likely when rosters and shifts were New Plymouth-based prior to April 2000 than it was after April 2000. It made no difference whether the LE was "working" from New Plymouth to New Plymouth (the interim solution introduced by Tranz Rail from April 2000 until staff issues were resolved), or living at New Plymouth and commuting to and from Stratford in his own time (the LE's elected manner to deal with the new structure introduced finally in October 2000).

2.4.5 The status of the travelling hours in September directly affects the interpretation of the Tranz Rail roster control procedures. However, even if the Tranz Rail view that they were not part of the shift is accepted the rostered and actual hours for the fortnight leading up to the incident were:

Base roster	101 hr
Mini roster	96.7 hr (104.7 hr including standby)
Actual hours (excluding road travel New Plymouth to Stratford)	106 hr

2.4.6 These hours are considered excessive without the effect of 14.7 hr travel included. It was apparent that both before the incident, and particularly after the incident, the overall Taranaki-based locomotive rosters were not managed to meet demand without requiring excessive fortnightly hours. Tranz Rail need to ensure that the available mix of relief shift links, standby shifts, and other defined and available means of supplying relief are managed without incurring such excessive hours, and recommendations have been made in Section 5 accordingly.

2.4.7 The new Stratford roster did not in itself extend hours of duty. However, the fact that it was operating with effectively 8½ LEs during September created an increased demand on the LEs that were available for duty.

2.4.8 The extra shift worked by the LE on Sunday, 17 September, was an undesirable addition. The LE should not have been offered this shift, based on his previous week's work and proposed work for the next week. There were no controls in the Wellington roster centre to avoid this happening, and no indication of how the defined 76 to 83-hr "acceptable" base-rostered shift range was related to mini rosters, actual hours worked and overlapping roster weeks.

2.4.9 The position was exacerbated by the long shifts he worked, and in particular the 12.3 hr shift on Wednesday, 20 September. The LE's annoyance at late finishing, and the request to drive himself home, resulted in his normal sleep pattern being disrupted on the evening of Wednesday, 20 September, with associated sleep loss on Thursday, 21 September.

2.4.10 The LE's perception was that the new Stratford-based roster was directly responsible for the extended shifts he had been required to work. In common with most New Plymouth LEs he was not in favour of the change of headquarters. This was not only understandable but predictable, and is relevant when considering the possible additional adverse affect this may have had on his sleep loss.

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 are included in Appendix 1.)

The analysis is based on 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.

2.5.2 Falling asleep uncontrollably becomes inevitable when biological sleepiness[5] exceeds a certain threshold. The factors defined in Section 2.5.1 contribute to the intensity of biological sleepiness.

[5] 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 overwhelmning leading to falling asleep uncontrollably.

Sleep history

2.5.3 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 incident had occurred 4 days prior to the interview with the LE.

However, the LE was an experienced shift worker who had developed a pattern of sleep for coping with night shift, including using a sleepout which he used to minimise disturbance to his daytime sleep. He also described in detail the routine he went through for taking naps when he was parked up waiting for a train to cross, a strategy that he used regularly. All of the strategies he described with regard to managing his sleep were practical and would be expected to be beneficial. They suggested a responsible attitude to prioritising and planning sleep.

Duration of continuous wakefulness

2.5.4 Laboratory studies have consistently shown that the longer a person stays awake, the sleepier they become and the more slowly and inaccurately they perform any type of work [6]. The LE reported sleeping from 1330 to 1630 on Friday, 22 September, and the incident occurred at around 2340, some 7 hr after the end of his last reported sleep period. Extended wakefulness was thus not a contributing factor in this event.

Sleep need

2.5.5 To be alert and able to function well, each person requires a specific amount of nightly sleep. A recent survey of the sleep of a large random sample of New Zealand adults (7,051 participants) found that people on average reported sleeping about 7.4 hr per 24 hr. However, 37% of the participants also reported that they rarely/never get enough sleep. If individual "sleep need" is not met, the consequences are increased sleepiness and impaired performance [3,5].

2.5.6 The LE described his usual daytime sleep as 4 hr in the morning (about 0700-1100) and 4 hr in the afternoon (about 1400-1800). In addition, he usually found the opportunity to nap for about an hour during the late shift. In general, night workers find it difficult to obtain such extended sleep during the day [2, 6-9]. It is not possible to verify the actual quantity and quality of sleep that the LE was able to obtain during these "sleep attempts". However, his awareness of his own sleep patterns and needs appeared to be high, and it may be that his pattern of daytime sleep reflected a relatively long sleep need.

On Tuesday 19 September and Wednesday 20 September the LE followed what he described as his usual pattern for late shift, which gave a total of 9 hr of sleep per 24 hr. In the national survey, about 1 in 16 men reported usually getting 9 hr of sleep or more per 24 hr.

Sleep loss

2.5.7 For most people getting 2 hr less sleep than they need on one night (an acute sleep loss of 2 hr) is enough to consistently impair their performance and alertness the next day. The reduction in performance capacity is particularly marked if less than about 5 hr sleep is obtained [5,10].

[6] The decline in performance associated with increasing time awake is superimposed on the rises and falls in performance associated with the cycle of the circadian biological clock. [2-4]

2.5.8 The effects of several nights of reduced sleep accumulate into a "sleep debt", with sleepiness and performance becoming progressively worse [11,12]. Recovery sleep after an accumulated sleep debt is usually deeper and more efficient, and the lost hours of sleep do not need to be recovered hour-for-hour. It typically takes 2 good nights for sleep to return to normal after sleep loss [13]. Reduced sleep is common during shift work, particularly among night workers [2,6-9].

2.5.9 The LE was working his fifth consecutive night shift when the incident occurred. The preceding week, he had also worked 5 consecutive night shifts. He was called back on Sunday, 17 September, to work a day shift. This would have restricted his opportunities for rest and recovery, although the hours booked were 0930 to 1650 and thus did not directly restrict his night-time sleep.

2.5.10 The LE's night shifts were consistently longer than they were rostered. Getting off later from the night shift generally restricts the duration of the sleep that is possible in the morning [9]. It reduces the "physiological window" of time available for sleep before the circadian body clock moves the brain and body into "awake mode", and sleep becomes very difficult. Shifts that exceed their rostered time also reduce the time available for all other aspects of life away from work, and could have an impact on an LE's ability to plan for sleep and other activities.

2.5.11 On the morning of Thursday, 21 September, the LE arrived home particularly late and was irritated about the circumstances of the 12.3 hr shift he had just worked. Because of his agitation and the circumstances of the late finish he was not able to take his normal morning sleep period, finally going to bed at 1300. He did not report napping on Thursday night. On Friday, both his daytime sleep periods were slightly shorter than usual and the timing of his crossings meant that he did not have time to nap on duty prior to the incident on Friday night. Thus his attempted sleep periods in the 48 hr prior to the incident were 6.5 hr shorter than his usual sleep pattern when on night shift.

2.5.12 In the best-case scenario, it could be assumed that he was fully rested when he started duty at 1950 on Wednesday evening. (It would, however, be unusual for a night worker, even someone motivated and experienced, to obtain adequate duration and quality of restorative sleep during the day.)

2.5.13 By the time he started work on Friday, the LE was very probably experiencing the effects of an accumulated sleep debt.

Sleep disorders

2.5.14 The restorative value of sleep, in terms of 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 making errors [12]. There are a large number of recognised disorders than can disrupt the quality of sleep [14]. There was no information available to suggest the possibility of a chronic sleep pathology, and the LE was not aware of any such problem.

Time of day of the incident

2.5.15 Biological sleepiness waxes and wanes across the daily cycle of the circadian body clock. There is a clear evidence, from laboratory studies, workplace studies, and incidents and accidents in a variety of industries, that people are most prone to making errors, and to falling asleep inadvertently, in the early hours of the morning and again in mid-afternoon [2,3,4,8,15].

2.5.16 A Swedish study that monitored 11 LEs during a day journey and a night journey (both of 4.5 hr) over a common route, found a sharp increase across the night shift in subjective sleepiness and in brain activity patterns indicative of sleepiness [16]. In this study, 4 drivers admitted to dozing off on the night shift, and 2 failed to act on signals while their brain activity patterns indicated that they were literally asleep on their feet.

2.5.17 A one-month study involving 10 locomotives on the German rail system suggests that LEs' vigilance is at its worst in the early hours of the morning [17]. Automatic brakings (caused when LEs 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 LEs failed to respond to a warning light that switched on every 25 seconds, as a vigilance device. The 0300 peak in hooter soundings was much more marked among LEs who were in the 4-6th hour of their shift at that time, than among LEs who were in the first 3 hr of their shift. This study included 2,238 automatic braking events and 19,769 hooter warnings.

2.5.18 The LE recalled that, immediately prior to the incident, he felt "really good, wide awake, really alert". A detailed study of 102 single-vehicle truck crashes in which the driver survived [18] showed that it is common for people in this situation to significantly misjudge how sleepy they really are.

2.5.19 The derailment occurred at about 2338, at which time the LE was about 4 hr into his shift. His biological sleepiness would be expected to be increasing rapidly towards its daily maximum. His increase in sleepiness (and decline in vigilance) due to the daily cycle of his body clock, would have been exacerbated by his prior sleep loss, and by his being 4 hr in the shift.

2.5.20 Based on the LE's prior duty history and self-reported sleep pattern, the time of day of the incident, and the nature of the derailment, there is a high probability that fatigue-related performance impairment was an important contributing factor in this incident. It is highly likely that the LE was asleep during the critical period when he should have begun braking the train to slow it down before entering the series of curves descending the Westmere bank.

Tranz Rail background

2.5.21 Tranz Rail had been active in evaluating and promoting action into aspects of LE fatigue, particularly since the mid-1990s. At the beginning of 1995, a roster change was implemented that permitted LEs to be rostered for duty periods that exceeded 10 hr (extended shifts). In November 1997, Tranz Rail requested that the Sleep/Wake Research Centre undertake a study on effects of extended shifts, in accordance with the agreement reached with the RMTU at the time rostered extended shifts were introduced.

2.5.22 The main aim of the study was to assess the prevalence and effects, of shifts that were rostered to exceed 10 hr (rostered extended shifts) as worked by Tranz Rail LEs. Information was also gathered on other issues of concern in the current rosters and on the health and job satisfaction of the LEs and the effects of shift work on their personal life. The study was commissioned by Tranz Rail, with the cooperation of the RMTU.

2.5.23 The summarised conclusions from this study, as numbered in its section 5.8, Conclusions and Recommendations, were:

1. The rosters significantly underestimated the number of shifts worked that exceeded 10 hours.
2. Long night shifts were viewed by all groups of participants as particularly challenging.
3. Sleepiness during and after rostered extended night shifts was a potential safety concern.
4. Long shifts were viewed as having a greater effect on life away from work than normal shifts.
6. Rostered extended shifts were not the only shifts that the LEs found challenging. Night work and late running were major concerns.
7. In the interest of better planning for rosterers, train controllers, and LEs, the rostered time of couplings that consistently run late should be reassessed.
8. It was recommended that LEs have a 2-day break at least once a fortnight, and preferably once a week.

9. Rostering 2 starts on the same day should be avoided as much as possible.

11. The study findings highlighted the need for regular opportunities to recover from sleep loss (2 nights of unrestricted sleep).
Existing education programmes for fatigue management, and the established procedures for diagnosing and treating LEs with obstructive sleep apnoea[7] needed to be fully implemented and widely publicised in the workforce.
A need for recurrent fatigue management training should be investigated, and appropriate strategies implemented.

12. Attention should be given to providing LEs with good information about diet, and to the food available to them at work. Opportunities and encouragement for LEs to be more physically active would be expected to be beneficial.

Specific comment on these conclusions as related to this incident are:

1. appears not to have been addressed
6. lists two key features of this incident, night work and late running
7. was directly relevant
8. was directly relevant.

2.5.24 At the same time Tranz Rail also developed with the Sleep/Wake Research Centre, an Alertness Management programme for rail operators (including LEs). From 1997, when the programme was introduced, to the end of the year 2000, about 35% of the approximately 500 LEs employed by Tranz Rail had been through the specific course supporting this programme. It is desirable that more impetus is given to putting all LEs through the course. Tranz Rail have recognised this and advised this will be addressed starting in 2001.

2.5.25 Tranz Rail supplied details of action taken since 1997 on issues highlighted by the 1997 study and programme. Although it was evident that a responsible and professional follow-up had been implemented, there were some notable gaps in areas such as management training, the control of fill-ins and relief, and LE alertness training. In general increased commitment will be required from Tranz Rail to gain maximum benefit from studies into LE fatigue issues if this type of fatigue-related occurrence is to be minimised.

2.6 Crashworthiness

2.6.1 Despite the speed and severity of the derailment and related damage to the cab of DFT 7064, the cab provided sufficient protection for the LE to avoid serious injury.

2.6.2 Although DC 4006 was unoccupied at the time, the separation of the cab could be a factor in future incidents, and its significance was therefore assessed.

2.6.3 The separation of the mounts on DC 4006 can be attributed to a combination of two factors. Firstly, the mounts themselves, including retaining brackets, were lower strength design than on the rest of the DC fleet as a possible consequence of DC 4006 being the prototype for the DC fleet and the mounts were then subject to change on following vehicles. Secondly, the cab struck the ground in disadvantageous circumstances due to striking the cutting face while moving in a relative rearward (long hood leading) direction which exposed the cab rear corner post (rear side wall edge) as the first part to strike the ground. This is a relatively flexible part of the cab structure due to the local door opening. The combination of a flexible sharp edge of the cab striking a mound at an angle pulled the cab side wall outwards, which would have generated a sharp sudden twisting force. The cab frame was severely buckled, which twisted the floor structure and wrenched the mounts apart. This action is unlikely to be replicated when a locomotive overturns onto flatter ground or the locomotive is running short hood leading. In these conditions the whole cab side would probably be evenly flattened and pushed inwards and not pulled outwards.

[7] a sleep disorder which causes repeated breathing stoppage.

2.6.4 All resilient cab mounts, including any retaining brackets used in Tranz Rail diesel locomotives will ultimately rupture or separate if subjected to high enough forces. What was most relevant in this case was that the cab had a weaker mount type and it impacted the ground in a manner for which protection was not designed.

3. Findings

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

3.1 Train 521 derailed 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 The LE should not have been offered an extra shift for Sunday, 17 September.

3.4 The base-rostered and mini-rostered hours for the LE for the fortnight 10 September to 23 September were excessive.

3.5 The actual fortnightly hours (either 119 hr including travel or 106 hr excluding travel) which would have been worked, including the day of the incident and excluding standby, would have been excessive.

3.6 The 12.3 hr shift worked by the LE on Wednesday 20 September due to the lack of a relief driver, and his annoyance with the late finish and transport arrangement on the morning of Thursday, 21 September, unnecessarily increased his sleep loss.

3.7 Although the LE was a senior driver with a responsible attitude to prioritising and planning sleep, and with no known sleep disorder, he was probably experiencing the effect of an accumulated sleep debt at the commencement of his shift on Friday, 22 September.

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

3.9 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 4 hr into the shift.

3.10 Although the Tranz Rail fatigue control regime had identified potential fatigue contributors and defined parameters and initiated actions to limit fatigue affect and improve alertness management, it had not been fully effective, as evidenced by:

- programmes to improve alertness management had reached only 35% of LEs over 3 years, and not the LE of Train 521
- Tranz Rail day-to-day roster controls involving shift changes and relief did not give due regard to established fatigue management principles
- Tranz Rail had no monitoring system to control total mini-rostered and actual hours per fortnight
- the effect of overlapping roster fortnights was not allowed for.

3.11 The roster associated with the change of headquarters of LEs from New Plymouth to Stratford was not a factor in the incident.

3.12 The faulty automatic resetting of the vigilance recorder removed a principal defence against microsleeps, although it is not certain that an operative vigilance system would have avoided the derailment.

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

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

4. Safety Actions

4.1 The number of available LEs on the Stratford roster has been increased from 9 at the time of the incident to 10. In addition, an LE is under training at Stratford.

4.2 Following the incident crew advisors and controllers at the Wellington roster centre were briefed on the need to ensure LEs were not subjected to difficult shift rotations when planning variations to master rosters and advised to err on the side of safety when requesting LEs to accept fill-in shifts and shifts outside the base roster pattern.

4.3 Tranz Rail have introduced a temporary maximum 98 hr per mini-rostered fortnight shift until all issues of maximum shift lengths are evaluated as part of a current review of rostering procedures being carried out in conjunction with the RMTU. Actual hours are being monitored by the manager train operations personally.

4.4 The possible effect of floating voltages from coupled locomotives has been addressed by a wiring modification. Until modifications are completed staff have been made aware of the correct set-up procedures to avoid this effect.

4.5 The alternative vigilance system project is being reactivated through the Locomotive Engineers' Council.

4.6 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. Additionally, a number of LEs who have shown signs of lapses of concentration have been taken through the existing package.

4.7 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 On 19 June 2001 the Commission recommended to the managing director of Tranz Rail that he:

5.1.1 put in place control measures to ensure:

- mini rosters are controlled within separate defined criteria compatible with the principles used in compiling base rosters
- the principles of rostering are applied to the overlapping weeks of consecutive rostered fortnights
- 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 On 25 June 2001 the managing director of Tranz Rail replied, in part:

5.2.1 017/01
Tranz Rail accept this recommendation.

5.2.2 018/01
Tranz Rail accept this recommendation.

5.2.3 019/01
Tranz Rail accept this recommendation.

Approved for publication 11 July 2001

Hon. W P Jeffries
Chief Commissioner

Appendix 1

1. National Transportation Safety Board 1994. Uncontrolled collision with terrain. American International Airways Flight 808. *Aircraft Accident Report 94/04.* Washington DC: National Transportation Board.
2. Akersted T 1991 Sleepiness at work: Effects of irregular work hours. In: Monk TH (ed), *Sleep, Sleepiness and Performance.* John Wiley and Sons Ltd: West Sussex. pp 129-152.
3. Dinges DF, Kribbs NB 1991 Performing while sleepy: Effects of experimentally-induced sleepiness. In: Monk TH (ed), *Sleep, Sleepiness and Performance.* John Wiley and Sons Ltd: West Sussex. pp 97-128.
4. Monk TH 1994 Circadian rhythms in subjective activation, mood, and performance efficiency. In: Kryger MH, Roth T, Dement WC (eds), *Principles and Practice of Sleep Medicine.* W.B. Saunders Company: Philadelphia. pp 321-33.
5. Carskadon MA, Roth T 1991 Sleep restriction. In: Monk TH (ed), *Sleep Sleepiness and Performance.* John Wiley and Sons Ltd: West Sussex. pp 155-167.
6. Monk TH 1994 Shiftwork. In: Kryger MH, Roth T, Dement WC (eds), *Principles and Practice of Sleep Medicine.* W.B. Saunders Company: Philadelphia. Pp 471-476.
7. US Congress, Office of Technology Assessment 1991. *Biological Rhythms: Implications for the Worker* (OTA-BA-463). Government Printing Office: Washing, DC.
8. Mitler MM, Carskadon MA, Czeisler CA, Dement WC, Dinges DF, Graeber RC 1988. Catastrophes, sleep and public policy: Consensus report. *Sleep* 11:100 – 109.
9. Gander PH, Gregory KB, Connell LJ, Graeber RC, Miller DL, Rosekind MA 1998 Flight crew fatigue IV : overnight cargo operations. *Aviation, Space, and Environmental Medicine B26-B36.*
10. Horne JA 1991 Dimensions to sleepiness. In: Monk TH (ed), *Sleep, Sleepiness and Performance.* John Wiley and Sons Ltd: West Sussex. pp 169-196.
11. Dinges DF, Pack F, Williams K, Gillen KA, Powell JW, Ott GE, Aptowicz C, Pack AI 1997 Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4-5 hours per night. *Sleep* 20: 267-277.
12. Roth, T, Roehrs, TA, Carskadon, MA, & Dement, WC, 1994. Daytime sleepiness and alertness. In: Kryger MH, Roth T, Dement WC (eds), *Principles and Practice of Sleep Medicine.* W.B. Saunders Company: Philadelphia. pp 40-49.
13. Carskadon MA and Dement WC 1994. Normal human sleep: An overview. In: Kryger MH, Roth T, Dement WC (eds), *Principles and Practice of Sleep Medicine.* W.B. Saunders Company: Philadelphia. pp16-25.
14. American Sleep Disorders Association 1997. *The International Classification of Sleep Disorders, Revised: Diagnostic and Coding Manual.* Rochester, Minnesota: American Sleep Disorders Association.
15. Monk TH 1990. Shiftworker performance. In: Scott AJ (ed), *Shiftwork. Occupational Medicine: State of the Art Reviews* (Vol. 5) Hanley and Belfus Inc: Philadelphia. pp 183-198.
16. Torsvall L and Akerstedt A. 1987. Sleepiness on the job: continuously measured EEG changes in train drivers. Electroencephalography and Neurophysiology. 66: 502-511.
17. Hildebrandt G, Rohmert W, and Rutenfranz J, 1974. 12 and 24 h rhythms in error frequency of locomotive engine drivers and the influence of tiredness. *International Journal of Chronobiology*. 2: 175-180.
18. National Transportation Safety Board 1995. Factors that Affect Fatigue in Heavy Truck Accidents. *Safety Study 95/01*. Washington DC: National Transportation Board.