The Waterfall train accident – the critical role of human factors

Dr. Andrew S McIntosh & Dr Graham Edkins*

School of Safety Science, The University of New South Wales, Sydney, Australia, 2052.
* Public Transport Safety Victoria, Department of Infrastructure, Victoria, Australia

Keywords: Accident investigation, deadman system, health, fatigue.

Abstract
The Waterfall train accident occurred on January 31, 2003 south of Waterfall station on the southern border of Sydney. The driver and six passengers were fatally injured in the accident. It was estimated that the Tangara train (G7) rolled over at a speed of 117 km/h on a left hand bend after the driver became incapacitated from a cardiac event. A Special Commission of Inquiry (SCOI) was established, headed by the Honourable Peter McInerney. This paper outlines the work the authors were engaged to do as human factors consultants to the SCOI and some of the contributory factors that arose as a result of the investigation.

Investigations conducted by the authors included: review of deadman design documents; structured interviews with drivers and guards; measurement of activation/deactivation deadman forces on Tangara trains; anthropometric analysis of the G7 driver and the wider driver population in a simulator, a review of medical standards, fatigue management practices, driver and guard training, as well as full background histories on the driver and guard.

The deadman system comprised a twist control on the master controller and a foot pedal, and was the primary driver safety control on the train. Its failure to initiate braking was one of the direct causes of the crash. At the end of the pedal distal to the driver an activation force of 95 N was required and deactivation forces were less than 50 N and greater than 200 N. Anthropometric analyses revealed the weight of the deceased driver’s leg/s alone and with no muscular effort was sufficient to maintain the system in an activated state. The driver weighed 118 kg. Train motion did not appear to influence this observation due to the driver console and footwell design.

Other human factors that contributed to the crash were: inadequate medical standards that were nor predictive or risk based; a culture of poor communication and inappropriate authority gradients between drivers and guards resulting in a failure to effectively communicate safety critical information; ineffective emergency training for staff, eg. the guard failed to apply the emergency brake; and poor systems to manage employee fatigue.
Introduction
The Waterfall train accident occurred on the morning of January 31, 2003 approximately 2 kilometres south of Waterfall station on the southern border of Sydney. The driver and six passengers were fatally injured in the accident. This paper reports on the critical role of human factors in the cause of the accident. The accident involved an outer suburban model Tangara (G7). The Tangara is a double-decker unit and was in a four car configuration. The accident came three years after the December 1999 Glenbrook train accident in the Blue Mountains close to Sydney. In both cases a Special Commission of Inquiry (SCOI) was established headed by Justice McInerney.

There was no obvious cause of the accident. Immediately after the accident there was a great deal of public speculation regarding the factors that may have led to the tragic loss of seven lives. This included whether ballast had been deliberately placed on the tracks to derail the train, whether the tracks had buckled due to the extreme temperatures the previous summer day, or if the train had ‘surged’ up to high speed and was ‘out of control’.

It was evident that the Tangara had derailed at high speed, rolled, collided with a stanchion, ran up an embankment and finally returned to the track area. The collisions resulted in substantial damage to the rolling stock and rail infrastructure. The inquiry determined that the Tangara had rolled over at a speed of 117 km/h on a left hand bend after the driver became incapacitated from a cardiac event. The guard had not applied the emergency brake, and while the deadman system was electro-mechanically operable, it had not functioned. Mechanical train stops were present between Waterfall station and the crash site, but G7 had encountered no red signals so the only possibilities for braking the train were the deadman system and the guard.

Overview of Inquiry and Investigations
Inquiries were conducted by the Ministry of Transport and by the SCOI. The SCOI was the primary public inquiry and involved very detailed investigations that were conducted in two main phases: causation and safety management systems (1). The initial investigations were divided into: infrastructure, rolling stock, human factors and management/administration. A lead investigator, Mr. Bob Lauby, was appointed by the SCOI for the first phase of the inquiry.

As the inquiry progressed public hearings were held at which investigators, as well as witnesses, rail personnel and other parties, gave evidence and were cross-examined. Further, as the infrastructure and rolling stock based investigations developed, it became evident that infrastructure defects had not caused the accident and that the train’s power and braking systems were functional at the time of the crash. The gradual elimination of purely engineering factors and evidence that the driver had suffered a cardiac event placed more emphasis on the need to direct resources into determining the human factors associated with the accident. It is generally agreed that human factors is an umbrella term for the study of people’s performance in their work and non-work environments. From the perspective of accident investigation, human factors is about understanding how people interact with systems, use equipment,
interpret policies, work with procedures and manuals, and operate within their working environment. It is also about their relationship with people.
The authors were appointed as consultants to the Commission to undertake investigations in these human factors issues.

**Human Factors Investigations**

Human factors investigations were undertaken in five main areas:

1. deadman system function,
2. driver and guard work and personal history,
3. fatigue and shift work,
4. safety culture and train crew communications, and
5. medical standards.

The authors were the primary investigators in the first four areas, and contributed significantly to the latter.

**Deadman System**

Deadman system investigations took a number of forms: design history, measurement of operating forces and functionality on G7 and representative Tangaras, anthropometric analyses, and system assessments with volunteers.

Anthropometric data were used to assess the weight forces that could be applied to the deadman pedal by the driver population and the deceased driver. Pedal forces were measured with a Mecmesin system. Tests were conducted in an ‘out of service’ cab on a non-revenue Tangara using 10 participants. Further tests were conducted using a driver training simulator with a sample of 41 participants. The population was chosen to include mainly drivers in the 90 to 120 kg range. Anthropometric measurements of stature, body mass, leg length, and pedal force were made. EMG was used to measure if the driver was applying any muscular effort. Descriptive statistics, regression and chi-squared analyses were conducted on the deadman and pedal force data.

The Tangara’s deadman pedal functioned as a lever that could be operated by one or both feet (figure 1). It was housed in an enclosed footwell under the console (figure 1). Activation and deactivation pedal forces were measured at the distal end of the pedal with reference to the driver. The forces were measured perpendicular to the pedal surface. When the investigation commenced there were no relevant force measurements available. The range of force through which the G7 system was active was 50 to 199 N; if the force was less than 50 or greater than 199 N the system deactivated. This was typical for Tangara pedals. With the force measured in the middle of the pedal the range was from 96 to 370 N. The deceased driver’s body mass was 116 kg. Estimation of the weight forces of one leg/foot/shoe and both were in the range 70 to 150 N. Based on anthropometry it was determined that it was possible for a driver of this body mass to rest one or both feet on the pedal without deactivating the system.
Figure 1: Schematic diagram of the deadman system: the pedal showing the floor, pedal, and cam/spring/micro-switch unit (left) and master controller T-Bar (right) shown in the deactivated position.

Ten ‘drivers’ participated in the test onboard a non-revenue service Tangara. A series of scenarios were assessed, with foot position, driving posture (including slumped over console) and body mass as the main independent variables. ‘Drivers’ were asked to operate the pedal with and without muscular effort. The mean body mass was 107 kg (SD=14). The footwell enclosure was found to restrict the movement of the legs and therefore, train motion did not appear to dislodge the legs from the pedal. The ‘dynamic’ tests indicated that all drivers above 105 kg could maintain activation of the deadman pedal with no muscular effort. Drivers also indicated that they found comfortable ‘effortless’ foot placements with which to operate the pedal. These tests were repeated in a static Tangara cabin simulator with the addition of the independent variable seat position and the measurement of the EMG signal from the lateral head of gastrocnemius. The latter confirmed that lack of muscle activation. Tests on 41 drivers (BM mean = 104 kg, SD=12) confirmed the previous observations and indicated that driver’s of body mass as low as 90 kg could maintain deadman activation without effort using both feet. As anticipated foot position on the pedal influenced these results. The tests reinforced strongly the opinion that due to his body weight the deceased driver could have held the deadman’s pedal in an activated position. The tests also revealed a range of problems with the pedal design, including the ability for a large proportion of the driver population to operate the pedal without effort and modes of inadvertent circumvention. An analysis of the SRA driver population (BM mean = 90 kg, SD = 16.9) indicated that approximately 18% of the drivers were at a high risk, and 26% at a medium risk, of being able to maintain the deadman activated without effort or while incapacitated (figure 2)
Figure 2: Estimate of proportion of SRA Tangara drivers able to hold the deadman's pedal in the activated position while incapacitated.

*Driver and Guard Work and Personal History*

A number of interviews with relatives, work colleagues and friends were conducted to develop a detailed work and personal background history of the deceased train driver. In addition, various documents were analysed including 31 police witness statements, investigator interviews with 8 employees working in the vicinity on the day of the accident, as well as a review of the driver’s disciplinary and safety incident records. Observations of train driver performance on the route taken by G7 also assisted in developing a profile of the work load and tasks the deceased driver may have been typically occupied with.

These interviews and document reviews revealed a psychological profile for the driver that was representative of an individual that was a happily married and devoted family man to his two children and grandchildren. There was no evidence that the driver was suffering from a level of stress that may have manifested in the form of distraction or inattention to his driving duties. The driver’s activities in the days leading up to the accident revealed a man actively planning for the future, eg. booking a family holiday, and planning for an overseas trip. Friends and family indicated that the driver was not a moody person, rarely got depressed and did not become overly worried about things. He was looking forward to returning to work after a significant period of recreational leave and according to his wife enjoyed his job and rarely complained about management. There was no past history of conflicts or disagreements with work colleagues, and close friends described him as reliable, dependable and honest, well liked by his work mates.

The driver had been employed by the rail organisation for 37 years. He began his career as a trainee engineer and was endorsed as a Class 5 driver operating passenger
trains in 1981. According to work colleagues the driver had an excellent knowledge of the Waterfall line from his many years of experience operating in the area. Employment records indicated a number of safety and disciplinary incidents during his driving career. Between 1967 and 2002 he was involved in a total of seven safety incidents, of which three were considered Major Offences involving Signals Passed at Danger (SPAD). In a career spanning 37 years, the number of SPAD’s are not considered unusual or indicative of a “cowboy” driver. A total of 24 disciplinary events were recorded between 1965 and 2002. These were mainly absences or lateness and the majority had been in the 1960s. The sheer number of incidents may also suggest poor management on the part of his train crew manager or problems he experienced with unrealistic shift patterns.

Medical records indicated that the driver consulted medical advice an average of 5 times annually between 1978 and 2002. This number of consultations is typical for most people in the general population. While most of the consultations were of a minor nature, his medical records indicated a problem with cholesterol. In 1994 his cholesterol level was 6.7 (any score greater than 5 for a male is considered high) and continued to rise to 8.6 in August 1999, prompting prescription of medication. In March 2002 he had not taken his prescribed medication for 12 months and it was restarted again combined with advice to reduce his alcohol intake and modify his diet. His medicals between 1991 and 2001 indicate significant weight gain from 99kg to 116kg in 2001. His Body Mass Index (BMI) taken in 2001 was 34.3, which is considered obese. His weight taken together with his inactivity and lack or regular exercise regime, indicated that he was a significant candidate for coronary heart disease. For example, using figures from his last medical in February 2000, his age, Cholesterol and Systolic Blood Pressure was entered into the Coronary Heart Disease Risk Factor Prediction Chart developed by the American Heart Association. This chart provides a risk output ranging from a low of 1 to a high of 32. The result for the driver for all risk factors is 20. For any score greater than 15 it is recommended that further investigation and monitoring of the patient be conducted. The autopsy examination conducted on the deceased driver confirmed evidence of significant coronary artery disease.

During the course of the investigation the guard, age 39 years, was unable to be interviewed due to ongoing treatment for anxiety and depression. A complete 72-hour history of the guard’s activities prior to the accident was unable to be determined due to his unavailability. His employment records indicated that he commenced work in the rail industry in 1982 and became a Guard Class 1 in July 1988. There were no records suggesting a pattern of disciplinary incidents. No details were contained in his personal files regarding safety incidents in which he had been involved in his capacity as a Guard. His personal medical records indicated a history of anxiety and depression focused on an inability to recall events. His medical history, presented an individual with poor coping skills and regular bouts of anxiety and depression. He sustained a number of physical injuries as a result of the Waterfall accident including a wedge compression crush fracture to the T11 vertebra and numerous lacerations and bruises. In summary, the guard’s medical history presents an individual characterised
by a self-defeating, personality, poor coping skills and a pattern of regular bouts of anxiety and depression.

Analysis of the fatigue impairment using FAID™

The influence of fatigue on the drivers performance was examined using a fatigue analysis tool known as FAID (Fatigue Audit InterDyne™) developed by the Centre for Sleep Research at the University of South Australia (2,3). The Waterfall accident occurred on the driver’s second consecutive workday after returning from a period of 5 weeks leave. The drivers’ fatigue level on the day of the accident was calculated as a FAID™ score of 37.9 and on the previous day 14.7. These scores are well within the operational tolerance of 80 for a high-risk task as that of operating a train solo. However, FAID™ does not take into account an individuals non-work activities and quality of sleep. As previously indicated in the driver’s 72-hour and 14-day history it appears that the relaxing nature of his holidays and family activities in the previous weeks leading up to the accident was an unlikely contributor to cumulative fatigue. According to his wife, the driver on the two nights prior to the accident slept restfully. Furthermore, he was well practised in preparing himself for shiftwork and had a pre-established routine. Based on this information, it appears that driver’s quality of sleep in the previous 72 hours was good and because it was only his second shift back after holidays, work related fatigue was an unlikely contributor to the accident.

While the background history on the driver indicated that he was not sleep deprived, research on shift workers indicates that workers returning to shift work after a long period of absence are more likely to make routine errors in the first few days back as a period of adjustment occurs. Rostering records indicated that on his first day back at work, the driver reported for duty over 2.5 hours late. It is quite possible that the driver was still trying to adjust to returning to shiftwork in his first few days back. This adjustment period may have had detrimental effects on his individual performance such as lack of concentration, difficulty in maintaining vigilance and slower reaction time.

The accident occurred on the guard’s 5th consecutive workday in a block of nine early morning shifts. The guard’s work roster, including actual hours worked, was analysed using the FAID™ fatigue modelling system. The guards fatigue level on the day of the accident was calculated as 90.8, well above the operational maximum of 80 and equating to a level of impairment equivalent to an alcohol intoxication level of 0.05 BAC, or greater. In the two days prior to the accident his FAID™ scores were 64.49 and 77.92 respectively. It is clear that his three early morning shifts (0323-1220) in a row were having a cumulative effect on his fatigue level.

Had the accident not occurred, and the guard had continued to work his planned roster of an additional four shifts, the FAID score would have peaked at 99 on day three and then dropped to 68 for the last day. A score of 99 is equivalent to a level of fatigue approximating 250% of the level of fatigue of the average working week. There is a high probability that the guard’s performance may have been influenced by the effects of work related fatigue.
Discussions with drivers and guards revealed that the typical workload of Guards in the stations leading up to Waterfall from Central is relatively high, due to a greater frequency of stops and higher passenger loads in the urban areas. However, between Waterfall and Helensburgh the workload decreased and guards typically report that this is the first time that they are able to relax. Given the consecutive nature of early morning shifts worked by the guard, it is possible that he experienced a micro sleep and therefore may have been slow to respond to the unusual speed of the train as it approached the 60-kmh speed board.

Safety Culture and Train Crew Communications

In addition to the interviews described above, structured interviews were held with a small number of guards and drivers at two main stations. The objectives of the interviews were to identify: procedures and practice related to emergency braking, patterns of guard-driver communication and team work, and deadman system function. All guards and drivers participated voluntarily. The following is a summary of the findings:

1. Ergonomics of the driver console were not considered to be particularly good. Both the hand control deadman lever and foot pedal were considered to be generally awkward and put a strain on the body of the users (arms, wrist, legs, ankles). Because of the strain of maintaining the required fixed postures some drivers resorted to jamming a foot between the deadman pedal and footwell heater.

2. There were known ways of circumventing the deadman controls, such as the with the foot pedal as noted above. Other ways that were mentioned were jamming the driver's red flag between the pedal and console and possibly the use of rubber bands to hold the deadman's twist grip on the master control in place.

3. The communications system in the driver’s and guard's cabins was considered to be very poor. A major flaw, was that there was no auditory signal to alert the driver to the guard initiating contact. Hence if a driver was asleep – he would not be woken up – or notice the guard's communication attempt.

4. Communication between the driver and guard generally was minimal, other than for routine matters. Significantly there was a major cultural/hierarchal barrier to a guard ‘pulling the tail’ (emergency brake cock) on a driver. Although it occurred, it would have been unusual for a guard to question a driver regarding the train's speed.

The cultural or hierarchal barrier, otherwise know as an “authority gradient”, was explored in more detail. Evidence given in train crew statements throughout the inquiry, as well as anecdotal evidence and informal discussions, indicated that there was some cultural animosity between drivers and guards, which may have discouraged guards from speaking up about safety issues, or more importantly taking intervening action, such as applying the emergency brake. Specifically, junior guards revealed a reluctance to challenge drivers on various issues. This cultural animosity is not surprising given that the two members of the “team” operated largely in isolation at opposite ends of the train and their communication was limited to bell signals or
occasional voice intercom. Drivers and guards often completed a journey without any face to face contact or voice communication and sometimes may not know who was at the other end of the train, particularly if there was a guard change mid-journey. Indeed there was no requirement for contact if personnel changes occurred during a shift.

The guard on the Waterfall train had an opportunity to take action to slow the train before it entered the curve and derailed. While the guards slow recognition of the evolving risk and associated fatigue level contributed to his inaction, at a more systemic level, guards were simply not equipped or trained in critical decision making skills or in undertaking well practised emergency action as a result of clearly defined risk events. In addition, at a cultural level there was a fundamental communication deficiency that discouraged guards from challenging a driver on his actions.

Medical Standards

A review of the medical standards was undertaken as they related to the cause of the accident. This point is dealt with in detail in the second paper. The driver of the Waterfall train had a history of cholesterol problems and obesity, which was not identified through the periodic medical examination regime implemented at the time. Had more rigorous standards been employed, and better rail industry familiarisation been provided to authorised medical practitioners, it is highly probable that the driver’s risk factors would have been identified and his driving certificate withdrawn until his health was managed to acceptable levels.

Discussion

The investigations into the causes of the Waterfall train accident revealed the critical role of human factors. These factors were not errors of commission, but rather an error of omission by the guard in failing to brake the train, and more importantly a failure to utilise a system design approach for train operation, in particular train safety, with adequate consideration for human factors. The latter resulted in latent conditions that were exposed by the incapacitation of the G7’s driver and inaction of the guard. The guard’s error has its antecedents in system flaws, procedures, communication, training, selection and culture.

Human factors investigations were able to provide valuable input into the inquiry and assist in the identification of the primary causes of the accident.

The Waterfall accident was not the first time in Australia that a major train crash had occurred due to driver incapacitation and deadman failure; the Southern Aurora crashed into a freight train in Violet Town in 1969 and the more recent 2001 accident in Footscray are two examples (4). Lessons learnt and implications are presented in a second paper.
Acknowledgements
The authors were engaged as consultants to the Special Commission of Inquiry into the Waterfall Rail Accident. The paper reflects the author’s opinions not those of the Inquiry. The authors acknowledge the exemplary work undertaken by many involved in the Inquiry and the specific support provided by Justice McInerney, his legal team, and Mr. Bob Lauby.

References