The Waterfall train accident – implications and lessons learnt
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Abstract
The paper describes the implications and lessons learnt from the 2003 Waterfall train accident, particularly in relation to onboard driver safety systems such as deadman and vigilance monitoring devices. The implications for organisations in ensuring that safety critical workers are fit for duty and trained to detect and manage errors are discussed.

From investigations into the Waterfall accident it was identified that there existed a number of inadequacies with the Tangara deadman system, in its efficacy to detect driver incapacitation. There was the potential for the deadman system to fail to initiate braking due to driver incapacitation in over 40% of the driver population. In addition to these observations, a range of methods to circumvent the system were identified, including wedging a flag pole to keep the footpedal depressed.

In an attempt to determine whether driver population and circumvention issues were an isolated NSW artefact, surveys were conducted with 112 suburban drivers in metropolitan Melbourne. While circumvention issues were not raised specifically, similar driver population demographics suggested that the same risk profile was evident. The Tangara’s deadman system design history revealed a failure to apply human centred design methods, and that the utility of the system had been eroded by modifications intended to satisfy occupational health concerns due to concerns about repetitive strain injury. Furthermore, previous concerns raised about the deadman device in NSW had gone unheeded, and a full system safety risk assessment had not been conducted.

Many of the deficiencies identified could be seen to reflect a culture of ‘on time running’ in NSW, eg. speeding and an inadequate safety culture. Medical standards, staff training and incident management were subject to scrutiny. The latter two highlighted the need for specific emergency training, improved crew communication, and a general change away from a culture of blame.

The Waterfall accident highlights the importance of an integrated approach to rail safety that brings together risk management, human factors and engineering methods, particularly in the design and testing of new engineered safety devices. Implications for organizations, and the need to foster a predictive risk based culture are discussed.
**Introduction**

The immediate causes of the Waterfall train accident and contributing factors were presented in a previous paper. This paper will focus on the lessons learnt and implications from the accident. The Special Commission of Inquiry and the previous inquiry into the Glenbrook accident, also in New South Wales, made numerous recommendations regarding all levels of rail operations (1,2). The accident revealed that the combination of medical standards, training, design, train and driver safety systems, and safety management systems were inadequate to control the risks inherent in rail operation.

In general, one important lesson learnt was that ergonomics and human factors can provide valuable input into the design and operation of rail systems. However, in this case, and other examples that were reviewed during the Inquiry, input was restricted largely to occupational health and was often of insufficient depth to provide critical input. In addition, rail standards specifications that referred to anthropometric data, eg. the footpedal device shall not be able to be accidentally circumvented by the dead weight of the operating limb or limbs within the male 97.5 percentile band, failed to provide support for designers that gave examples of relevant population data and their application. This failure was evident in other areas, as described in the paper.

**Train and Driver Safety Systems**

The accident revealed that the deadman system did not reduce to an acceptable level the risk of a train remaining under power if the driver became incapacitated. Furthermore, it found that warnings regarding this flaw had not been addressed in the Tangara’s operational history.

A review of design documents, reports and SRA correspondence revealed that the flaws had been identified as potential problems early in the Tangara’s operational life. The design process and selection of pedal activation and deactivation forces was not documented, neither were the forces clearly specified. Early in the Tangara’s operational history there was a major redesign and refit of the driver’s console. The 1991 Worksafe project provided valuable ergonomic input that lead to the modification of the driver's console, controls and displays (3). The function of the deadman's foot pedal as a central component of the Tangara's safety systems appears to have been largely ignored in these projects. The focus of the pedal redesign was improving comfort and reducing the risk of lower limb musculoskeletal disorders, even though it was explicitly stated that safety had the priority over other considerations. Therefore, the primary importance of safety was recognised on one hand, but design efforts appeared to focus on ergonomic considerations in the area of occupational health. Human factors data and design documents are required to assist in the translation of intent to practice.
**Victorian survey of driver safety systems**

The findings of the inquiry also triggered other rail operators and safety regulators to review the operation of their systems. A survey of Victorian suburban train drivers was conducted by the authors to support a review of driver and vigilance operating systems conducted by the Victoria Department of Infrastructure. Some aims of the survey were to examine whether driver population and circumvention issues were an isolated NSW artefact or more widespread. The survey consisted of a structured questionnaire completed by the drivers and measurement of stature, body mass and pedal forces using a simulated seat-pedal arrangement. Participation was voluntary and anonymous. One hundred and twelve drivers participated and basic population and anthropometric data are presented in table 1.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experience as Suburban Driver (yrs)</td>
<td>110</td>
<td>14 ± 8</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>111</td>
<td>45 ± 8</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>111</td>
<td>175 ± 8</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>111</td>
<td>87 ± 13</td>
</tr>
<tr>
<td>Vertical Foot-Pedal Force (N)</td>
<td>107</td>
<td>79 ± 19</td>
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Table 1: The foot pedal force was measured with participants wearing their normal shoes.

The trains used by the drivers had both a foot and hand pilot valve (deadman system). The mean and median percent of time in which the foot pilot valve was used was 53% and 60% compared to 47% and 40% for the hand pilot valve. The foot pilot valve control and the plunger type hand pilot valve control were considered the best of the four controls, with the twist style being the worst.

Drivers were asked whether they experienced discomfort while driving and to describe the nature of it, eg. location of symptoms and duration. Seventy-five percent of the drivers did experience discomfort or pain while driving and using the pilot valve, with the upper limb most affected (56%). Seventy percent of drivers found that changing posture relieved the pain or discomfort, however there was a small residual (14%) who complained of pain/discomfort lasting greater than 24 hours after the end of a shift. This highlighted the need to consider comfort and occupational health issues in system, however without sacrificing the intended utility of the safety device, and demonstrates how uncoordinated design activities commence.

Surveys of driving postures and feet positions on the pedal showed a large range of positions for each individual and across the population. Fourteen percent of the drivers reported wedging the heel of their shoe into the pedal mechanism, thus jamming it in an activated position. While most drivers reported that the deadman system had triggered braking at some point while driving, normally due to bumpy track, they also reported that it rarely deactivated if they were drowsy or inattentive. With regards to a question asking drivers to recall what would happen if they rested...
one or two feet on the pedal with no muscular effort, 52% reported that the pedal would remain activated with one foot and 26% reported it would remain activated with two feet.

Figure 1 is a comparison of operational forces for Victoria suburban trains and the measured foot-pedal forces from the driver population sampled. The figure does not consider specific foot placements or the lever action of the pedals. It confirms that without further adjustment for foot position on the pedal or the use of two feet, about 50% of the drivers could through the weight of the leg simply hold the pedal in an activated position. The results are consistent with the driver surveys.

![Figure 1: Comparison of measured range of foot forces (with shoes) to activation and deactivation forces on Melbourne trains. In comparison the deactivation forces on the Tangara were 50 N (df1) and 199 N (df2).](image)

The Victorian survey confirmed that the deadman system problems identified in the Waterfall accident were present in the Victorian driver population and train fleet. The possibility of drivers inadvertently circumventing the deadman function by wedging their foot/feet in the pedal, the failure of the pedal to deactivate when the driver was relaxed, and the biomechanical analyses pointed to similar latent conditions. In comparison to the Victorian trains, the deactivation force range on the Tangara was much greater. As a result, the deadman device installed on suburban trains in Victoria is being progressively enhanced with a task linked vigilance system.

**Risk Management**

One of the most disturbing pieces of evidence in the Inquiry was that the risk of an incapacitated driver passing a signal at stop was assessed to be "Barely Tolerable" for Outer Suburban Tangaras (OST) as it had been for Double Deck Intercity Cars (DDIC). While task linked vigilance systems had been progressively installed on the DDICs from November 1999 to treat those risks, OSTs were not modified. Furthermore, ‘ergonomic’ assessments of the drivers’ consoles and controls focussed on occupational health criteria, not on safety, and there appeared to have been no
formal human factors evaluation of the prototype task linked vigilance system. Human factors considerations are important in risk management.

**On-Time Running**

When the broader streams of evidence and information from the Inquiry, from official sources and in the press were combined, it became apparent that the culture of ‘on time’ running was of great significance at the time of the Waterfall accident. One of the recommendations from the Glenbrook inquiry was that data loggers be fitted to all trains. The G7 unit had a data logger, but it had not been activated at the time of the accident. Therefore, relevant data that would have accelerated the investigation were not available. One of the obstacles to activating the data loggers was the perception that drivers may have exceeded speed boards to meet the timetable. Therefore there was resistance to their introduction. Further, the culture of speeding may have influenced the G7’s guard not to ‘pull the tail’, as it may have not appeared to be abnormal that the train was travelling too fast, until too late.

The program to install and activate data loggers appears to correspond with the deterioration in peak period on-time running to about 80% in December 2003 reaching only 48% in February 2004 (4). On-time running was defined as being < 4 minutes late. This problem was worse in off-peak services and known well by Sydney rail commuters. The Hon. Michael Costa was reported in Hansard to have said that “we have said consistently that data loggers have reduced the running speeds of trains because they operate almost as fixed speed cameras” (5). Implicit is an acknowledgement that running in excess of the speed boards was commonplace and, probably, necessary to meet the timetable. An analysis conducted by the Independent Transport Safety and Reliability Regulator (ITSRR), the Rail Safety Regulator, suggested that there may have been a 2% slow down in transit time due to behavioural change and that other factors may have been equally or more important, eg. dwell time, crew management and incident management (4).

**Medical Standards**

Given the health risk factors outlined in the previous paper for the driver, the medical examination regime for train crew was examined to determine whether it was sufficiently rigorous enough to identify such candidates and manage them accordingly. The medical procedures used by the rail organisation were compared to various industry standards including those of other Australian rail operators, civil aviation and current practices for drivers of commercial vehicles. This review identified that the medical procedures in place at the time of the Waterfall accident, were less than satisfactory based on industry benchmarks.

The medical guidelines were very broad, providing only limited detail in determining medical fitness for work. For example, there was no recommended course of action for staff found to be borderline risk in regards to heart disease, diabetes, sleep apnoea or are drug and alcohol dependent. Clinical interventions were largely left to the discretion of the medical examiner. There was no formal process for the selection and authorisation of medical practitioners to undertake occupational medical assessments, and because there was no induction process the system relied on “word of mouth” for
handovers of rail staff. There was also no central or in-house expertise within the rail organisation for medical practitioners to consult with regarding special cases.
In particular, the medical guidelines provided little direction with regard to the identification of psychological health issues or detailed requirements about follow-up procedures for staff involved in critical stress incidents and who might experience symptoms of post traumatic stress disorder (PTSD).

With regard to obesity, the standards referred only to applicants for employment who must have a Body Mass Index (BMI) less than 30. There were no guidelines for existing employees and no detail about what interventions were required for current employees who have a BMI greater than 30.

This investigation also identified a pattern of internal correspondence between management, in which significant deficiencies with the standards were acknowledged but not acted upon over a seven-year period.

It was also observed that there had been a 10 kg increase in the mean body mass of the SRA drivers in the decade preceding the Waterfall accident. The combination of increased driver age, potential increased risk of incapacitation related to increased body mass, and the function of the deadman system are latent conditions that cross the medical, engineering and human factors domains.

In summary, the medical standards used by the rail organisation were characterised by:
- a lack of guidelines on the qualifications, selection and monitoring of authorised medical practitioners,
- limited guidelines in relation to determining medical fitness for work for a number of medical conditions including cardiovascular disease, obesity, sleep disorders, psychological health and drug and alcohol dependency,
- a failure to address contemporary health issues (eg. HIV) and to account for more recent advances in occupational medicine and clinical practice.
- less frequent periodical assessments required under operator standards compared to the vast majority of other standards.

**Fatigue Management**

The rail organisations approach to fatigue management was found to be deficient. They did not apply FAID™ to the periodic or daily “local” level rosters to determine if work rosters were fatigue inducing. In practice master level rosters change significantly at the local level due to shift swaps between train crews, or depot managers attempting to fill the gaps from personnel absenteeism fluctuations. In other words, often the master level rosters are a poor representation of the actual hours worked of a given train guard or driver.

Furthermore, rostering practices within the organisation allowed drivers to be rostered to return to work on an early morning shift following a period of significant leave (as had the driver of the Waterfall train), and thus did not take into account issues associated with circadian disruption or other fatigue elements at the micro level. No guidelines, training or education material has been provided to train crew to help them manage a return to work under these circumstances.
Training
While the organisation had conducted some joint safety training for guards and drivers, there was no evidence that this training encouraged these two parties to operate effectively as a team. Other industries such as aviation, had implemented crew resource management (CRM) training to encourage better coordination and communication (6).

Training within the organisation had typically being directed at drivers and guards, operating as individuals in isolation, rather than as a team. Had the organisation conducted a training needs analysis, or utilised a risk based approach to curriculum development, hazards such as authority gradients between drivers and guards, the need for critical decision making skills, the importance of standard phraseology for communication, and staff reticence to report safety issues, may have been identified and addressed.

The role of guards in relation to safety was ill defined and overly focused on customer service requirements. Procedures and specific training in guards being able to recognise a speeding train, initiating the appropriate action and their role in emergency situations were deficient.

Safety Culture
Although the organisation had a documented safety management system, it was the application of this system in practice that was not clearly evident. A proactive and systems wide approach to safety hazard identification and a prevailing attitude amongst many senior managers that the Waterfall accident was an “unfortunate accident”, were indicators that there was not a dominate safety “consciousness” throughout the organisation. In contrast, the main imperative driving the organisational culture appeared to be on-time running. The imbalance between safety and on-time running became a factor that influenced day to day decision making and ultimately led to many of the causal factors identified in the Waterfall investigation.
Conclusions

A holistic human factors-risk management-engineering approach is required to assess issues related to safety and reliability in rail. The accident and subsequent inquiry showed that without consideration for all of these approaches, latent conditions will not be identified, or will be created.

There are many human factors lessons arising from this investigation for transport operators, policy makers, investigators and regulators alike. In particular:

- Designers and engineers require relevant human factors data, as do those involved in system procurement.
- Systems and components cannot be modified to satisfy occupational health objectives without consideration for safety.
- The management of fatigue involves more than monitoring employee work rosters but should include comprehensive education, guidelines, policies, quality assurance processes and targeted training at supervisory level staff to ensure that workers are fit for duty.
- Medical examination standards for safety workers need to be periodically reviewed to ensure that they are predictive and preventive of potentially incapacitating medical conditions and updated in line with contemporary advancements in medical science.
- That initial and recurrent training programs practically reinforce the concept of teamwork to ensure that individuals do not operate independently but are supportive and cooperative in the conduct of their duties. In addition, specific procedures and a supporting periodic training regimen for teams in regard to critical decision-making skills such as that adopted within the aviation and healthcare industries.
- The importance of ongoing independent reviews of an organisation’s safety culture to identify values, norms and attitudes that may have a potentially adverse influence on safety.
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